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Lynn Eden

Center for International Security and Arms Control



**Constructing Destruction:
The Making of Organizational Knowledge
about the Effects of U.S. Nuclear Weapons**

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PREFACE

Scholars have explored the invention and development of U.S. atomic weapons, the decision to drop atomic bombs on Hiroshima and Nagasaki, and later decisions regarding the development of the hydrogen bomb, the nuclear stockpile, and nuclear war plans. Not examined has been how the U.S. government developed its understanding of the damaging effects of nuclear weapons, in particular, how those involved in studying nuclear weapons effects and in planning nuclear war developed knowledge of nuclear weapons effects for incorporation into U.S. strategic nuclear war plans.

After devastating use in 1945, and a half century of testing and analysis, it is generally assumed by those in the nuclear weapons effects and war planning communities that the matter is well understood. Blast effects of nuclear weapons are the primary cause of damage. Other effects, particularly large-scale mass fires that could be caused by the searing heat from thermal radiation emitted by nuclear weapons, are less predictable and less important than blast effects.¹

The issue has not always been closed. From the time of their invention, it was understood that nuclear weapons were unprecedented in the scale of destruction they wrought, and that serious scientific effort would be required to understand the damaging effects of these weapons. The U.S. government sponsored this scientific effort. The resulting activities were expensive and wide-ranging. Knowledge was seriously pursued and hard

¹Some other effects, such as initial radiation and residual radiation in contaminated particles of fallout, have been the subject of numerous investigations, but have never been considered for incorporation into U.S. strategic nuclear war plans. Others, such as electro-magnetic pulse, may have been considered for incorporation into war plans, particularly recently. However, all of these effects, while significant, fall outside the scope of this book.

won, if always in the practical context of understanding and predicting the effects of nuclear detonations as weapons of war.

Constructing Destruction is about how, in the early post-World War II period, the U.S. government developed highly detailed knowledge about the blast effects of nuclear weapons for use in war planning and, at the same time, did not develop the same level of knowledge about the intense thermal effects of those weapons -- that is, the extreme heat and resulting large-scale fires from nuclear weapons. As knowledge was developed regarding blast effects, it was codified into handbooks that military officers and others who were not highly technically trained could routinely use as an aid in nuclear targeting for predicting damage to targeted structures. Thermal effects were not codified and, consequently, were not incorporated into the fundamental analytical routines involved in nuclear targeting.

The process by which an officer solved a targeting problem by referring to this handbook is what I call a "knowledge-laden routine." A routine because it was a perfectly mundane set of operations done repeatedly in nuclear targeting; it comprised the everyday stuff of organizational life. And knowledge-laden because it carried within it a very expensively acquired set of expert understandings and predictions about the behavior, or what is called the phenomenology, of blast waves caused by nuclear weapons detonations and the response of structures to those blast waves.

My questions regard these knowledge-laden routines. Why did the U.S. military develop knowledge-laden routines that took account of blast effects but not thermal effects, and why has this system, much refined, endured to the present day? In other words, given the destructive mission set for nuclear weapons, in devising U.S. nuclear war plans, from the earliest

post-World War II plans to present planning, why have U.S. planners not incorporated the extremely destructive thermal effects of nuclear weapons, and instead, in calculating damage, focused exclusively on blast?

My interest in these apparently arcane, not to say morbid, questions developed a number of years ago over many lunch time conversations with my then Stanford colleague Ted Postol. Postol had written on the devastating damage that would be caused by the mass fire ignited in large part by thermal radiation from a nuclear detonation. It was Postol's view that the government's methods for calculating damage effects seriously understated the damage that would occur. If so, there were serious policy implications. It would mean that the United States had procured many more nuclear weapons than necessary to cause the level of damage expected in U.S. war plans. It would mean that, in the event of use, the effects could be considerably more devastating than anticipated. Finally, it would mean that consideration of whether to use nuclear weapons could be predicated on false information. For example, a political decision to employ a "limited" option to signal constraint could result in far greater devastation than political leaders might understand.

Postol was puzzled about why the U.S. government did not take thermal radiation and resulting fires into account. Postol's wonderment was compounded by his knowledge that non-nuclear incendiary weapons had been extensively used toward the end of World War II and that a body of expertise on incendiary effects had been developed. What happened immediately after the war? And why, as far as we knew, had the system put in place after the war persisted in the half century since?

Postol, a physicist, did not know how to go about researching such questions. I was not sure I did, and in any case I was involved in another project. But little by little I found myself trying to understand what had happened.

As I got hooked, I began to see that lurking in this puzzle was a very broad issue: how actors in organizations try to understand the external world and how they act in, and on, that world. How do actors in organizations decide *what* they need to know and what they do *not* need to know? How do they decide what evidence to generate and to ignore? By what criteria do they measure and evaluate evidence? In short, how do organizations structure their understandings of reality? And, how do these understandings become embedded in organizational capabilities and routines?

I saw that the investigation would have to be at once about science, technology, organizations, and historical process. The analytical system developed for predicting blast damage from a nuclear detonation was simultaneously a conceptual result of *scientific* understandings of the effects of nuclear weapons, a *technological* invention used as a tool to predict damage in nuclear targeting, and an *organizational routine* that both shaped and embodied organizational conceptions of mission and of the world outside; finally, the analytical system devised was a result of complex *historical* processes.

What began as a research note grew into a much larger project. When I began what is now *Constructing Destruction*, I had two distinct historical investigations in mind. The first was to try to explain the outcome of a recent decade-long effort by a few scientists, doing exploratory studies for the Defense Nuclear Agency, the agency of the U.S. government responsible for

understanding nuclear weapons effects, to incorporate the damaging effects of thermal radiation into nuclear targeting routines. When I began, a decision had not been reached. I did not know whether the government would incorporate those effects or not. Thus, my explanation would have to be able to explain *either* outcome. This forced me to take the idea of historical contingency very seriously; I could not escape understanding that whatever the outcome would be, it could have gone differently. (As it has turned out, the decision was made in early 1992 to stop such work and to make no further effort to incorporate thermal effects into analytical routines for predicting damage in nuclear targeting. I did not find this out for some time after.)

No matter what the outcome, I knew that what was at stake could only be explained by examining the early post-World War II period, when knowledge about the blast effects of nuclear weapons was first developed and codified. This was the second investigation that I had in mind when I began this project. In this period, the newly formed U.S. Air Force was the organizational center of these activities. Air Force Intelligence, particularly those within its Targeting Division, began efforts to analyze and codify nuclear weapons blast effects. These same people played a significant role in shaping inquiry in post-war atmospheric nuclear weapons tests.

However, in investigating the early post-war period, I found myself, willy-nilly, in the historian's regress. Despite important discontinuities between what had gone on during World War II and after, it was also clear that certain continuities, such as understandings within the Air Force of its mission, were crucially important. I decided that my investigation would have to extend back to the formative period of the U.S. Air Force in the first third of this century and its later experience in World War II.

Although my questions first ran backwards in time, I present my historical analysis in the conventional order, from the earlier period to the later. The argument I present explains why and how, historically, an organizational understanding developed in which damage caused by blast effects seemed to be more predictable than damage caused by thermal effects.

Chapter 1 provides the empirical basis for my puzzle. I describe the blast and thermal effects of a modern strategic nuclear weapon and compare the predicted damage to the much lower levels of damage predicted in U.S. government calculations.

Chapter 2 lays the theoretical basis for my argument. I first present several possible explanations for why thermal effects were not taken into account in damage predictions. The most important of these claims is that the answer lies in the physical world itself: thermal effects are far more varied, and hence, less predictable, than blast effects. Another important possible explanation centers on organizational interests. I reject these and offer my own explanation. Organizational pre-understandings shaped later inquiry, resulting in much greater knowledge regarding blast effects than thermal effects. This resulted from the choices of actors, not from "nature" itself. In other words, pre-existing organizational ways of knowing and doing -- or "frames" (a concept I elaborate in this chapter) -- incorporated assumptions and knowledge about the world, articulated or assumed purpose, defined problems, and shaped, in focusing organizational attention and resources, the search for solutions.

Chapter 3 begins the historical argument. In a nutshell, my argument is that from early in its history, the major frame organizing the activities of the U.S. Air Force was the doctrine of precision strategic bombing. Within

this doctrinal frame, the most important cause of deliberate damage to targets was widely understood to be blast caused by high-explosive bombs. Activities regarding the comprehension, prediction, and optimization of blast damage became deeply instantiated into the organizational routines of the U.S. Air Force. The integral connection in the U.S. Air Force between precision bombing doctrine and blast weapons stands in contrast with British understandings and practice which emphasized area bombing doctrine using incendiary weapons. In the United States, incendiary weapons and the fire damage produced by such weapons received few organizational resources and little attention before World War II. With the war, a great deal more attention was focused on understanding and solving problems regarding both blast damage and fire damage. However, the attention and resources invested in the prediction and optimization of blast damage was far greater than the attention and resources invested in the prediction and optimization of damage from fire.

Chapter 4 explores the immediate post-World War II period. The invention and use of an unprecedented new weapon, the atomic bomb, notwithstanding, the immediate post-war period was one of great continuity with wartime understandings. The applied scientific exploration of this new weapon was done in the context of the continued dominance of precision strategic bombing doctrine and the continued focus on blast effects. This focus strongly influenced early analyses of the effects of atomic weapons. From the earliest post-war period, blast damage from atomic weapons was considered to be more predictable than fire damage caused by those weapons. At the same time, precision bombing doctrine and organizational attention to blast effects shaped the expanding organizational capacity of the Intelligence Division of

the U.S. Air Force to target atomic weapons and to predict the damaging effects of those weapons.

Chapter 5 demonstrates how this new organizational capacity -- expertise and knowledge -- was deployed in atmospheric nuclear weapons tests conducted after the war and how it shaped analysis of these tests. More attention was devoted to the measurement of damage to targets from blast effects than from thermal effects. As a result, substantial progress was made in comprehending blast phenomena and in predicting damage from blast. As the methodology for predicting blast became increasingly sophisticated -- for example, making refined adjustments for the much greater yields possible with hydrogen bombs -- the contrast between the ability to predict damage from blast and from fire became ever greater. By the mid-1950s, the analysis of these tests led to an important analytical invention, the VNTK system, which codified new knowledge about nuclear weapons effects and very substantially increased organizational capacity to predict blast damage.

The knowledge and capacity to predict damage from blast effects, but not from thermal effects, became self-reinforcing: the ability to solve certain kinds of problems led to the continual refinement of organizational capacity to predict damage from blast effects. The VNTK system, a knowledge-laden organization routine, was continually polished but remained relatively static over many years. At the same time, no methodology was developed for predicting damage from thermal effects. Not unreasonably (although incorrectly), most involved in predicting damage from nuclear weapons explained the inability to predict damage from thermal effects to greater variation in thermal effects themselves, rather than to organizational choices

that led to a relative lack of effort to develop predictive tools regarding damage to targets from thermal effects.

Chapter 6 jumps ahead to the late 1970s. I examine how organizational knowledge was challenged for a period of over a decade and how the VNTK system might have been broadened to include thermal effects. I then explain the conjunction of historical circumstances, including the end of the Cold War, that led to the end of the effort to incorporate thermal effects in damage prediction for use in nuclear war planning.

The research methods that I used were eclectic and varied by period. For the period from the early history of the Air Force through World War II, I relied primarily on secondary work, supplemented by some documentary sources and a few interviews. For the early post-war period, I relied primarily on unclassified and declassified archival sources, including declassified official histories which had been originally classified as confidential, secret, or top secret. I obtained a number of important documents through formal requests made under the Freedom of Information Act. Although much remains classified, enough has been declassified to discern the most important aspects of the history. I was crucially guided in my questions, guesses, and intuitions by a number of interviews with civilians and retired officers who had been involved in the early atmospheric testing of nuclear weapons or who had analyzed nuclear weapons effects in the early post-Cold War period or later. Without these interviews, I could not have made my way through this period: I could not have found a number of important documents, I could not have made sense of the documentary evidence, and I could not have filled in what the documents do not say. Quite late in the process, I was fortunate to be able to do a crucial interview which not only

filled in even more, but also allowed me to confirm the main lines of my analysis. For the recent period, I relied almost entirely on interviews, plus a few documents.

Secrecy has made this investigation difficult, but in forcing me to look beyond documentary sources, it has added an important dimension, at least for me personally. I never dreamt in my college days when I marched on Washington against the War in Vietnam that I would, years later, enter offices in the Pentagon and in suburban Washington which were locked vaults and that within I would find insightful and sympathetic people of great integrity and dedication from whom I would learn a great deal.

Indeed, I have accumulated many debts in the researching and writing of *Constructing Destruction*. [Acknowledgments follow.]

Chapter 1

THE EFFECTS OF NUCLEAR WEAPONS¹

¹Sources for the discussion below include:

Samuel Glasstone and Philip J. Dolan, eds., *The Effects of Nuclear Weapons*, 3rd ed., Prepared and published by the U.S. Department of Defense and the Energy Research and Development Administration (Washington, D.C.: U.S. Government Printing Office, 1977).

R.D. Small and H.L. Brode, *Physics of Large Urban Fires*, PSR Report 1010, Final Report Contract No. DCPA01-79-C-0291 for Federal Emergency Management Agency, Washington, D.C. (Santa Monica, California: Pacific-Sierra Research Corp., March 1980); R.D. Small and H.L. Brode, briefing, "Fire Program Plan Presentation," Prepared for Defense Nuclear Agency, DNA001-80-C-0065 (Santa Monica, California: Pacific-Sierra Research Corp., March 11-12, 1980) [looks like initial attempts to get funding from DNA for this research project]; Harold L. Brode, *Large-Scale Urban Fires*, PSR Note 348, Prepared for the Defense Nuclear Agency, Contract DNA001-80-C-0065 (Santa Monica, California: Pacific-Sierra Research Corp., December 1980); H.L. Brode, *Review of Nuclear Test Peak-Overpressure Height-of-Burst Data*, PSR Note 353, [contract number for whom?] (Santa Monica or Los Angeles, California: Pacific-Sierra Research Corp., November 1981); Dr. H.L. Brode, briefing for the Defense Nuclear Agency, "Fire from Nuclear Bursts in Urban Areas, April 1982; D.A. Larson and R.D. Small, *Analysis of the Large Urban Fire Environment*, PSR Report 1210, Final Report Contract EMW-C-0747 for Federal Emergency Management Agency, Parts 1 and 2 (Los Angeles, California: Pacific-Sierra Research Corp., July 1982 and November 1982); Harold L. Brode and Richard D. Small, *Fire Damage and Strategic Targeting*, PSR Note 567, Contract DNA 001-82-C-0046, Sponsored by Defense Nuclear Agency, Washington D.C. (Los Angeles, California: Pacific-Sierra Research Corp., June 1983); H.L. Brode et al, *Fire Damage to Urban/Industrial Targets*, PSR Report 1936, Contract DNA001-88-C-0055, Prepared for Headquarters Defense Nuclear Agency, Washington D.C. (Los Angeles, California: Pacific-Sierra Research Corp., 25 July 1989), Vol. 1, *Executive Summary*, Vol. 2, *Technical Report*: unclassified sections from Section 1, "Introduction," Section 3, "Fire Damage from Thermal Ignitions," Section 5, "Fire Spread," Section 6, Methodology for Predicting Fire Damage," Section 7, "Uncertainties and Variabilities," Section 8, "Comparisons with Historical Urban Fires," Section 9, "Results for Sample Targets," Section 10, "Conclusions and Recommendations" and appendices; [include?] Lloyd E. Johnson, Harold L. Brode, Richard D. Small, *Analytical Models of Weapon Effects for Nuclear Warfare Simulation*, PSR Note 596, Contract DNA001-83-C-0015, Sponsored by Defense Nuclear Agency, Washington D.C. (Los Angeles, California: Pacific-Sierra Research Corp., July 1984).

Theodore A. Postol, "Possible Fatalities from Superfires Following Nuclear Attacks in or near Urban Areas," so and so, ed., *The Medical Implications of Nuclear War* (Washington, D.C.: National Academy Press, 1986), pp. 15-72 (check whole cite); plus his article on nuclear weapons effects in *Encyclopedia Americana*, plus his "Targeting" article in Carter, Steinbruner, Zracket, eds., *Managing Nuclear Operations* (Washington, D.C.: Brookings Institution, year), pp. xx-xx.

The shock wave produced by an air-burst atomic bomb is, from the point of view of...disruptive effect, the most important agent in producing destruction.....[T]he other characteristics of an atomic bomb which can be employed in warfare, such as the presence of thermal and visible radiations, neutrons, gamma rays, and fission products, are, at present, not serious competitors in the production of damage by a bomb which is burst in the air....A reason for the superiority of air blast as a producer of damage is found in the low air shock pressures...required to damage the majority of man-made structures.

Samuel Glasstone, ed., *The Effects of Atomic Weapons*, prepared for and in cooperation with the U.S. Department of Defense and the U.S. Atomic Energy Commission, under the direction of the Los Alamos Scientific Laboratory (Washington, D.C.: U.S. Government Printing Office, June 1950), p. 45.

Let us imagine a 300 kiloton strategic nuclear weapon detonated near the earth's surface. This is the approximate yield of most modern strategic nuclear weapons. It is far greater in yield than the 12.5 kiloton weapon detonated at Hiroshima and the 20 kiloton weapon detonated at Nagasaki, and far less than the largest warheads formerly deployed in the U.S. and Soviet arsenals.²

²Many weapons in modern arsenals have yields of 300 kilotons or more. The Russian SS-18 warhead is estimated at 550-750 kilotons; Russian SS-24 and SS-25 warheads are both estimated at 550 kilotons (Stockholm International Peace Research Institute, *SIPRI Yearbook*, 1994 (Oxford University Press, 1994), p. 288. In the United States, the Minuteman IIIa, MX/Peacekeeper, and Trident II systems are estimated to have warhead yields of 335, 300, and 475 kilotons respectively (Robert S. Norris and William M. Arkin, "NRDC Nuclear Notebook," *Bulletin of the Atomic Scientists*, Vol. 51, No. 4 [July/August 1995], p. 79). Describing the effects of a 300 kiloton yield weapon slightly understates the damaging effects of weapons of higher yield. However, the range and intensity of nuclear weapons effects do not change drastically with changes in yield from 300 kilotons to several hundred more.

From the mid-1950s to the late-1960s, the Soviets introduced into their arsenal thousands of warheads with yields from 1 to 20 megatons, including 1100 Tu-16 Badger A warheads and 1500 Yak-28 Brewer warheads, estimated at 1 megaton each; almost 100 Mya-4 Bison A warheads and almost 300 SS-9 Scarp warheads, estimated at 20 megatons each; and hundreds of other weapons with yields of 1 to 6 megatons. See: Thomas B. Cochran, William M. Arkin, Robert S. Norris, and Jeffrey I. Sands, *Nuclear Weapons Databook*, Vol. IV: *Soviet Nuclear Weapons* (New York: Harper & Row, Ballinger Division, 1989), Table 1.1, "Soviet Nuclear Weapons (1953-1988)," pp. 3-4, and Table 5.1, "Strategic Offensive Nuclear Forces (mid-1988)," p. 99; Randall Forsberg, ed., *World Weapon Database*, Neta Crawford, Vol. II: *Soviet Military Aircraft*, Institute for Defense & Disarmament Studies (Lexington, Massachusetts: Lexington Books, 1987); Robert Berman and Bill Gunston, *Rockets and Missiles of World War III* (New York: Exeter Books, 1983), "Summary: USSR," pp. 85-86.

From the mid-1950s to the early 1960s, the United States introduced into its arsenal high-yield nuclear weapons, from thousands of warheads in the 1 megaton range, including Mark 15, B-43, and Minuteman I and II warheads, to weapons with yields in the 9 to 10 megaton range, including almost a thousand B-36 warheads, 500 B-41 warheads, 340 B-53 warheads, and 60 Titan II warheads. Additionally, the United States deployed several hundred warheads with yields estimated in the 10-15 megaton range and hundreds of warheads with yields

At its peak energy output, a 300 kiloton weapon would produce at its center temperatures about four to five times the temperature at the center of the Sun, temperatures in excess of 200 million degrees Fahrenheit, or about 100 million degrees Celsius.

Upon detonation, an extraordinary amount of energy, about 3×10^{14} calories, would be released within a few hundredths of millions of seconds. Initially, nearly all of this energy would be in the form of fast-recoiling nuclear matter which would be nearly instantly deposited into the surrounding environment. A chemical explosion of comparable yield would release almost all its explosive power in the form of a powerful expanding shock wave. However, more than 95 percent of the energy initially released in a nuclear explosion is in the form of intense light. Since this intense light is of very short wavelength (it is soft x-rays), it would efficiently be absorbed by the air immediately surrounding the weapon, heating it to very high temperatures and creating a "ball" of fire.

Because the early fireball would be so hot, it would quickly begin to expand violently. Almost all of the air that originally occupied the volume within and around the fireball would be compressed into a thin shell of superheated, glowing, high-pressure gas. This shell of gas, which would continue to be driven outward by hot expanding gases in the fireball interior, would itself compress the surrounding air, forming a steeply fronted

ranging from 1 to 5 megatons. See: Thomas B. Cochran, William M. Arkin, Robert S. Norris, and Milton M. Hoenig, *Nuclear Weapons Databook*, Vol. II: *U.S. Nuclear Warhead Production* (Cambridge, Massachusetts: Ballinger Publishing Company, 1987), Table 1.2, "U.S. Nuclear Warhead Production 1945-85," pp. 10-11; Thomas B. Cochran, William M. Arkin, and Milton M. Hoenig, *Nuclear Weapons Databook*, Vol. I: *U.S. Nuclear Forces and Capabilities* (Cambridge, Massachusetts: Ballinger Publishing Company, 1984), Table 1.5, "Inactive Delivery Systems (1945-present)," pp. 10-11, and Table 3.1, "U.S. Nuclear Weapons Stockpile (1983)," p. 39; E-mail from Stan Norris [Robert S. Norris] to Lynn Eden, August 11, 1995; and Robert Berman and Bill Gunston, *Rockets and Missiles of World War III* (New York: Exeter Books, 1983), "Summary: United States," p. 31.

luminous shock wave of enormous extent and power.

By the time the fireball approached its maximum size, it would be a highly luminous ball more than a mile in diameter. Half a second after the detonation began, it would be at its brightest. Its surface, which would mask the much hotter interior of the fireball from the surroundings, would still *radiate two and a half to three times more light and heat than would a comparable area of the Sun's surface.* At a range of approximately one and a third miles from the explosion, the fireball would for a fraction of a second shine over 5,000 times brighter than would a desert sun at noon. In other words, the fireball would deposit its radiant energy on surfaces at a rate 5,000 times greater than that of a desert sun at noon. At a range of three and a half miles, energy would be deposited at a rate roughly 600 times that of a desert sun at noon. Even at a range of six to seven miles, the fireball would shine roughly a hundred times brighter than would a desert sun at noon. Further light and heat energy from the fireball would be released over a period of two to three seconds.

This enormous release of light and heat would create an environment of almost unimaginable lethality. Vast amounts of thermal energy would be deposited. This would cause extensive fire ignitions over large urban and suburban areas. In addition, the extreme compression of air would cause an intense blast wave and accompanying high-speed winds. The blast wave and accompanying winds would pulverize many structures by crushing and tearing them apart. The blast wave would also boost the incidence and rate of fire-spread by exposing ignitable surfaces, releasing flammable materials, and dispersing already burning materials throughout the environment. Within minutes of a detonation, fire would be everywhere, as numerous spreading

fires from ignitions and dispersed firebrands would begin to coalesce into a mass fire covering a ground-area of tens of square miles. This developing mass fire would begin to heat enormous volumes of air that would buoyantly rise as cool air from the fire's periphery was pulled in to replace it. Within tens of minutes after the detonation, the pumping action from rising hot air would generate superheated ground-winds of hurricane force in the fire-zone, which would mature into a "mass" fire -- a hurricane of fire -- of remarkable scale, intensity, and lethality.

The tremendous amounts of light and heat released by a nuclear detonation is typically measured, at any given range from the detonation, in terms of energy deposited onto exposed surfaces. This deposition of energy is reported in units of calories per square centimeter. The amount of energy deposited decreases with range from the detonation point.

A deposition of 10 cal/cm² is roughly equal to the amount of energy deposited at 1.1 miles from the ground zero of the much smaller 12.5 kiloton nuclear detonation at Hiroshima; at this range, a nearly circular perimeter of mass fire was initiated. This fire covered an area of roughly 4.4 square miles and burned with great intensity for more than six hours after the initial explosion. Roughly 80,000 people immediately died from the combined effects of the fire, blast, and nuclear radiations.³ The fire that occurred from the 19 kiloton atomic detonation at Nagasaki is often characterized as less than a mass fire,⁴ but this is incorrect. Nagasaki did not sit on a flat plane surrounded by relatively distant mountains, as did Hiroshima, but rather was located in an upwardly sloping valley. At Nagasaki, the valley walls acted

³some source on Hiroshima

⁴Murray Sayle, for example, writes, "No true firestorm broke out" at Nagasaki, in "Did the Bomb End the War?" *New Yorker* (July 31, 1995), p. 56.

like the walls of a giant fireplace and the upward slope of the valley acted like a flue through which the hot gases from the mass fire flowed. As a result, fire-generated winds flowed, and fires spread, from low to high ground-areas up the flue created by the valley's walls. The area burned out by fire at Nagasaki was not circular as at Hiroshima, but the fire produced was a mass fire.⁵

Based on the experience at Hiroshima and Nagasaki a very strong case can be made that 10 cal/cm² is a good first estimate of the range within which a mass fire could be expected in a city attack. Analysts often double the deposition of energy to 20 cal/cm² to provide a more conservative measure of the range within which a mass fire would be expected, but the physical evidence nevertheless indicates that a deposition level of 10 cal/cm² is a good predictor of the range at which mass fires would be initiated.⁶

The wake of the powerful passing blast front contains very high winds. The intensity of the blast wave and the speed of the accompanying winds are determined by the "overpressure," associated with the blast wave. The overpressure is defined as the air pressure above normal air pressure at sea level. In the United States, it is most often reported in units of pounds per square inch or psi (the normal unshocked air pressure at sea level is 14.7 psi).⁷ According to one succinct definition, "The overpressure in the blast wave acts in all directions and can be thought of as simply a rapid increase in air pressure above ambient atmospheric pressure. As a target is engulfed by the blast wave, overpressure acts to crush it. This crushing pressure lasts for a

⁵source on Nagasaki. Maybe get casualties, area burned, deposition of calories if available. Ted has diagrams of the areas that burned at both Hiroshima and Nagasaki.

⁶Von Hippel et al, International Security use 20 cal. Postal, SuperFires, uses 10 cal.

⁷This is equivalent to 1×10^5 Pascals in SI units. SI [check] stands for "Standard International," also known as the Metric International System.

time duration which is dependent upon the weapon yield as well as the peak pressure level.”⁸

The winds that accompany the blast wave also exert powerful forces on structures in the path of the shock wave; these forces are often described as a “dynamic pressure,” a pressure due to the wind motion. The wind-drag forces on a targeted structure depend on the shape of the structure. As a structure changes shape and disintegrates under the action of overpressure and wind, there is a complex interaction between the winds and the many pieces of the disintegrating structure. This interaction can result in greatly enhanced levels of damage to certain kinds of structures.

At a range of 1.3 miles from a 300 kiloton detonation, the leading edge of the blast wave would be compressed to a pressure of approximately 10 psi. The blast wave would be sufficiently powerful to overturn blast furnace superstructures, collapse and rupture gas mains in steel mills, and overturn cranes in shipbuilding yards. It would also be able to tear apart light building structures and knock in the exterior walls of many large buildings facing the detonation point. At this overpressure, conservative measures of damage from blast predict severe damage to heavy industrial installations such as steel plants and chemical plants.⁹ Military structures such as silos or underground bunkers that have been specifically designed to withstand nuclear effects are typically much more resistant to the effects of a nuclear detonation. In order to inflict significant damage against these structures, overpressures of hundreds to thousands of pounds per square inch may be specified.

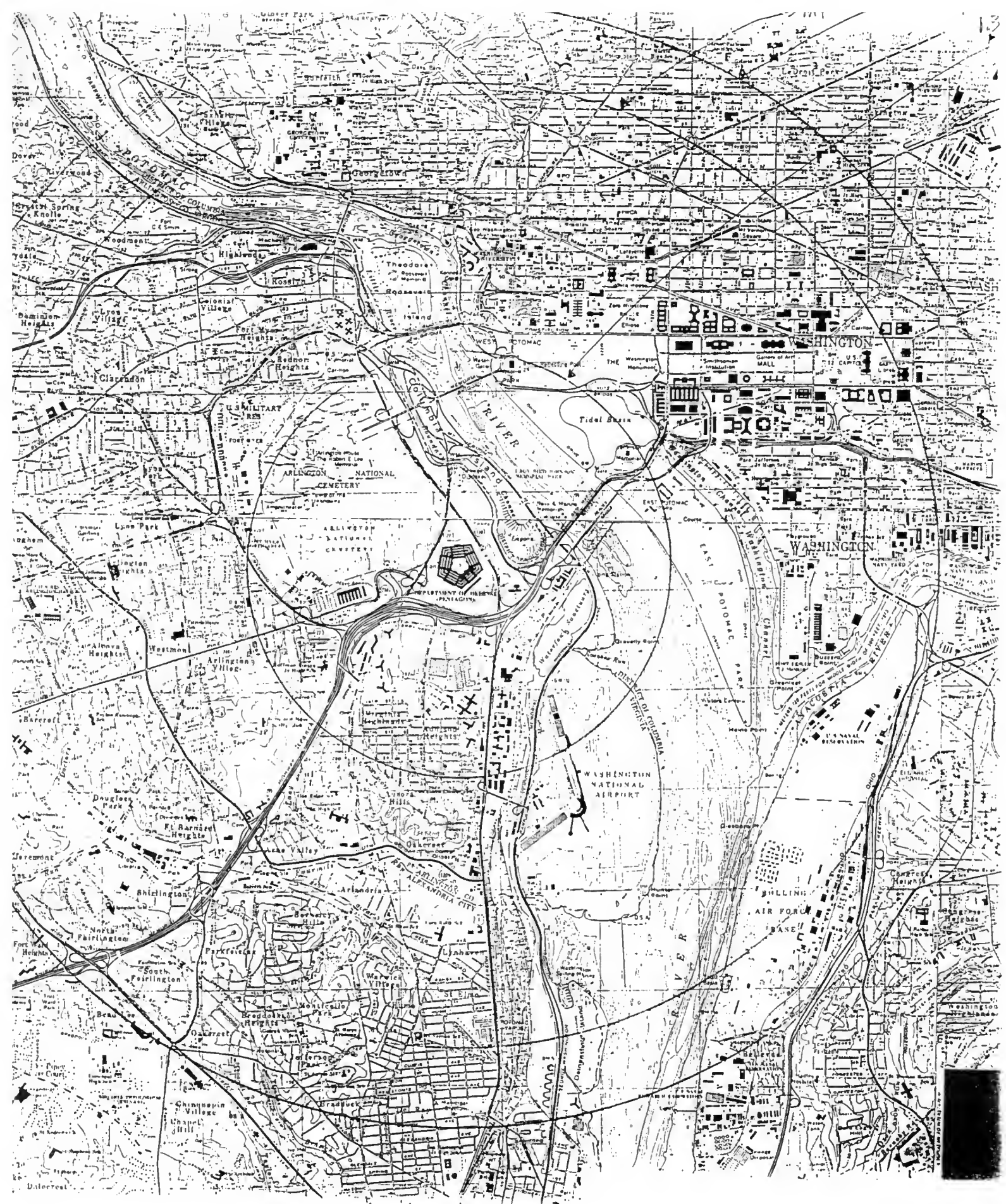
⁸Defense Intelligence Agency, *Physical Vulnerability Handbook--Nuclear Weapons* AP-550-1-2-69-INT (Washington, D.C.: Defense Intelligence Agency, 1 June 1969, with change 1 [1 September 1972] and change 2 [28 January 1974]), p. I-1.

⁹*Physical Vulnerability Handbook*, pp. xx-xx. See discussion in Appendix A below.

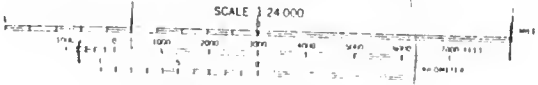
To better understand the effects of nuclear weapons, let us now imagine the effects of a 300 kiloton nuclear weapon detonated at the Pentagon, a short distance from the center of Washington, D.C. Let us imagine a near-surface burst in order to maximize blast damage to the Pentagon and to the many underground structures beneath and adjacent to it.

At 1.3 miles from the detonation, that is, at a range extending into National Airport, largely encompassing the Virginia Highlands and Addison Heights neighborhoods in south Arlington, including almost all of Arlington National Cemetery, and, in Washington, D.C., reaching to the Lincoln and Jefferson memorials (see map), about 175 cal/cm² of radiant energy from the fireball would be deposited onto exposed surfaces over a period of seconds.¹⁰ (This is over fifteen times the energy deposited at the edge of the mass fire that destroyed Hiroshima. Of course, even greater energy would be deposited closer to the detonation.) Throughout the area -- including, for example, at Arlington National Cemetery -- grass, vegetation, and leaves on trees would explode into flames, and the surface of the ground would explode into superheated dust. Flames and black smoke would be spewed out from all combustible materials illuminated by the fireball. Flammable material inside buildings, such as paper, curtains, and upholstery, directly exposed would burst into flame. Buildings with such flammable material would include residences in Arlington and offices and shops in Pentagon City and Crystal City. Trees and telephone poles would physically recoil from the flaming emission of gasses. Birds in flight would drop from the sky in flames and clouds of insects would create spectacular fireworks displays as they flashed into burning carbon. Sheet metal surfaces would melt and buckle. The air

¹⁰Unless otherwise stated, I am assuming 10 miles visibility. Regarding lesser visibility, see below, pp. xx-xx.



LAND SERVICE
SURVEY INDEX



CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929
BATHYMETRIC CONTOUR INTERVAL 1 METERS WITH SUPPLEMENTARY
0.5 METER CONTOURS. DATUM IS MEAN LOW WATER
THE RELATIONSHIP BETWEEN THIS DATUM AND THE
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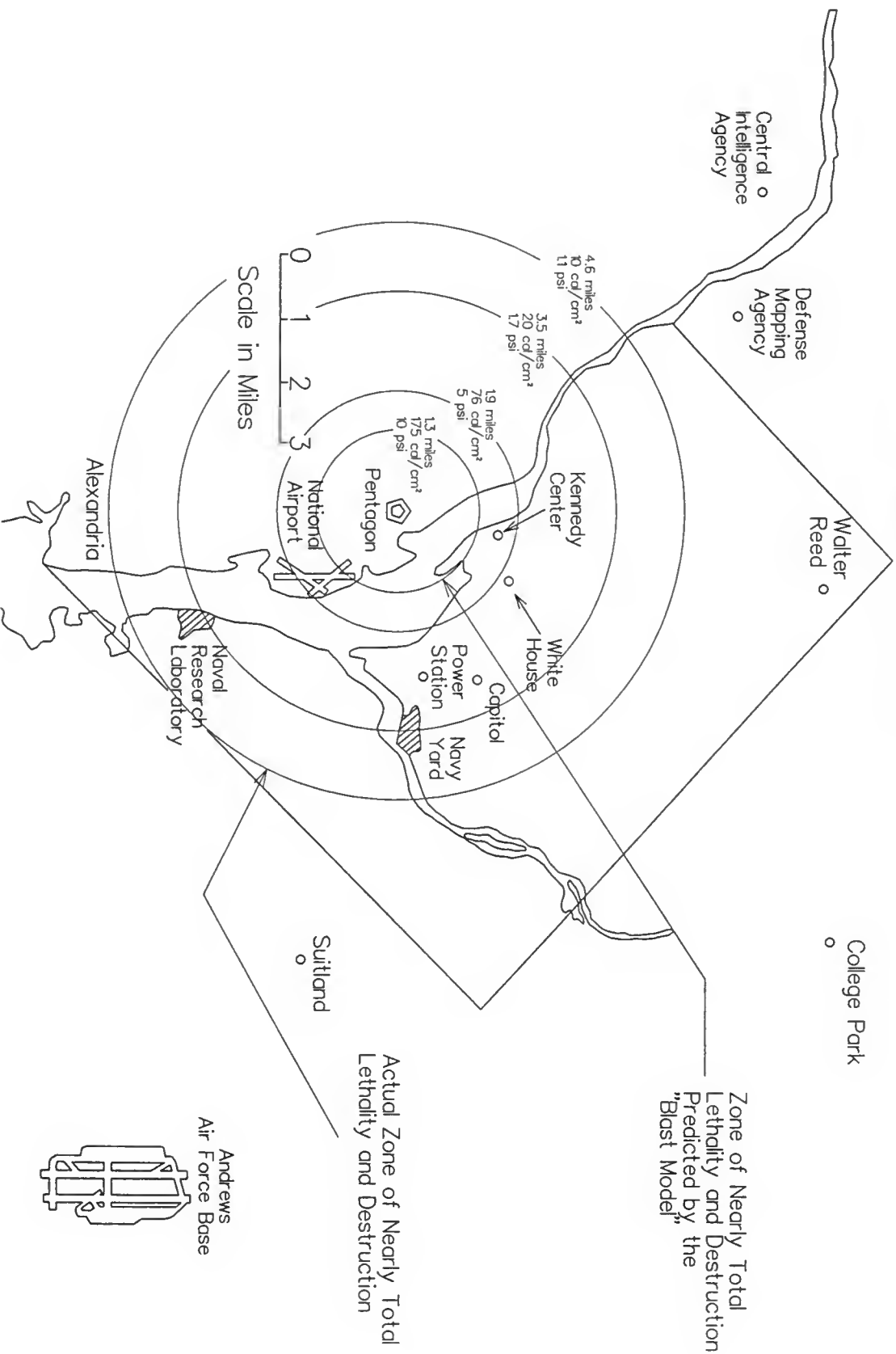
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WASHINGTON WEST D.C.

Effects of Detonation at the Pentagon of 300kt Nuclear Weapon Near—Surface Burst

10 Miles Visibility



would be filled with dust, fire, and smoke. Persons directly exposed to the illumination of the fireball would be instantly killed. Their clothes would explode violently into flames, and their exposed skin would be carbonized, that is, instantly burnt to charcoal. Those shaded from the direct light of the fireball might also be burned by gasses emanating from nearby surfaces and blinded from the enormously intense flash of diffusely reflected light.

(Just beyond this range, about 1.6 miles from the Pentagon, aircraft located at Washington's National Airport, would be exposed to a light flash from the fireball more than three thousand times brighter than a desert sun at noon, and the thermal fluence would be 111 cal/cm². At *half* the intensity of the light from the fireball, which would occur at a range of 2.2 miles from the detonation, the thermal effects of approximately 55 cal/cm² would be sufficient to melt and warp aluminum surfaces on aircraft. Interior sections of the aircraft illuminated by the fireball would burst into flames. The tires of the aircraft would catch fire, as would those of any service vehicles near the aircraft. Fuel hoses would also catch fire, and it is almost certain that the planes would be burning after the attack. As important, the tremendous thermal stresses on the aircraft from differential heating of exposed surfaces would cause control surfaces and other components that are fit to high tolerance to jam and to be inoperable. At the full fluence, all these effects would occur, and they would be even more severe.)

About four seconds after the detonation, the shock wave would arrive at a distance of 1.3 miles from the detonation. As noted above, at this range, the leading edge of the blast wave would be compressed to a pressure of approximately 10 psi. As the shock wave passed over all but the strongest structures, it would engulf them in a region of relatively high pressure and

crush them from all sides. It would also generate ferocious 300 to 400 mile per hour winds that would persist for about a second and a half (hurricane force winds are about 70 miles/hour).¹¹ These winds would work in combination with the crushing blast wave overpressure to tear structures further apart. At this range wood-frame and residential brick buildings would be completely destroyed. Large concrete and steel office buildings, such as those at Pentagon City, would not be knocked down, but all nonsupporting interior walls and doors would be completely shattered and blown at high speed through the interior of the structure. The blast wave would also blow many window frames out of supporting walls, and window frames and glass would be turned into missiles, along with heavy desks, tables and filing cabinets, chairs, and other interior furnishings. Although the buildings would likely remain standing, within minutes their interiors would be burning infernos of splintered walls, doors, and other combustibles. Other structures at this range, such as the Arlington Memorial and George Mason Memorial bridges would almost certainly not collapse; however, anyone caught in the open or even sheltered behind these structures would either be killed instantly or die seconds or minutes later. A structure, such as the Long Railroad bridge, might burn; it would certainly suffer enough structural damage to render it unsafe for use by trains.

As structures broke up, the high winds would act on structural elements, tearing them from attachments and causing them to explosively disintegrate into smaller pieces. Some of these pieces would then become large destructive projectiles that could hit yet other objects, causing still

¹¹The destructive force of winds from a nuclear detonation increase somewhat more rapidly than the square of the wind velocity. This is because the winds are generated as a byproduct of the blast wave and the air density in the blast wave also increases with wind velocity. Thus, 300 to 400 mile per hour winds will create wind-forces on buildings twenty to thirty times larger than those from hurricane force winds.

further damage and creating yet more projectiles for the winds to carry. The winds would also be laden with fine superheated dust and large numbers of small fragments generated by the pulverizing combined action of the light-flash and blast wave. The superheated dust-laden winds would be strong enough to overturn heavy vehicles such as cars, trucks, and railroad cars. In addition they would disperse violently burning pieces of shattered structures that had been ignited by the light from the fireball. For example, at Pentagon City, about seven tenths of a mile from ground zero, the blast wave would be more powerful and destructive than that at ground zero in Hiroshima.¹² Within a half second of the detonation, light from the fireball would melt asphalt in the streets, burn the paint off surfaces, and cause metal surfaces to melt. The interiors of vehicles and buildings in line-of-sight of the fireball would explode into flames. Roughly one second later, seven hundred mile per hour winds would arrive with the shock wave, tossing burning and disintegrating vehicles into the air like leaves in a wind-storm. The compressed air and winds associated with the shock could cave-in building faces and might even topple some or all of the massive office buildings. Even if the buildings and their exterior walls remained standing, their interiors would be splintered to shrapnel and dust by supersonic shock-driven winds channeled through explosively disintegrating window openings.

Seconds after the passage of the blast wave, suction effects created by the distant rising fire ball would cause the winds to reverse and start blowing toward the detonation point at perhaps 50-70 miles per hour. This would cause some objects, such as trees, to flip and face toward the point of

¹² The blast wave overpressure at this range would be roughly 40 psi, about equal to that which occurred at ground zero in Hiroshima. However, the duration of the blast wave would be about two to three times longer, and the amount of thermal radiation deposited by the fireball would be roughly three times as large. These factors would result in a generally greater level of destruction to the Pentagon City area than that which occurred at ground zero in Hiroshima.

detonation, rather than away.

At a range of 1.3 miles, a monumental reinforced concrete and steel structure would probably not be knocked down; it would however be devastated. All non-supporting interior walls, and all windows and doors, would be blown out. In addition, the intense light-flash from the fireball would have set fires throughout the structure, consuming the entire contents. Visibility in surrounding streets would be very low from dust and smoke in the air, and fires would be violently burning everywhere. Within tens of minutes, the entire area¹³ would be consumed in a mass fire, which I will describe in more detail below.

What would be the effects at a range of 3.5 miles, almost three times the 1.3 mile distance discussed above? This range extends over a mile past the White House and includes all of the Mall, the Capitol Building, and much of the surrounding Capitol Hill neighborhood. The monumental structures on Capitol Hill, such as the Capitol Building, the House and Senate Office buildings, and the Library of Congress, are located approximately 3 miles from the Pentagon. Union Station, a massive building, is also located near the Capitol Building, less than 3.5 miles from the Pentagon. These are

¹³Although the Pentagon is located near a relatively wide river, fires would be set by the detonation in very large areas on both sides of the river. For example, on the opposite side of the river, an area two to three times the size of the destroyed area at Hiroshima, roughly eight to twelve square miles, contains combustible high fuel loading structures that would be consumed in a mass fire following the detonation. This fire alone would generate ferocious winds and air temperatures. The larger area-fire burning across the river from downtown Washington would generate similar winds and air temperatures. The direction of fire winds in regions located near the edge of the fire zones and river would be modified by the region of nonburning water. However, the overall wind pattern from these two huge and nearly contiguous fire zones would be similar to that of a single huge fire.

The interested reader can easily verify this claim on a small scale by observing that the flames from two burning matches will merge to a single flame when they are separated but close. This occurs because hot gases rising from each flame can only be replaced by cool air from zones that are most distant from the other flame. As a result, air flowing in from zones unheated by either fire drives each flame towards the same centerline, causing the flames to coalesce when they are sufficiently close.

reinforced concrete framed multistory buildings of two to ten stories of earthquake resistant design. They are among the strongest civilian buildings in the world. The surrounding neighborhood is mostly composed of private two to four story dwellings with brick load-bearing walls surrounded by numerous trees.¹⁴ The 3.5 mile range also encompasses most of the Navy Yard and Bolling Air Force Base, includes northern Alexandria and much of Arlington, as well as Georgetown, Connecticut Avenue past the Taft Bridge, and Dupont Circle, Logan Circle, and Mt. Vernon Square (see map).

At a range of 3.5 miles, the light-flash from the fireball would be much less severe, delivering about 20 cal/cm² to objects in line of sight (double the thermal fluence at the edge of mass fire at Hiroshima). The shock wave would also be much less severe, having a peak overpressure of 1.7 psi. The shock wave would persist for well over 2 seconds and would be accompanied by near hurricane speed winds of 60 miles per hour. It would arrive about 12 to 14 seconds after the light-flash from the fireball, almost a quarter of a minute after the detonation began.

Although the blast would be of greatly diminished strength, the fireball at this much greater range would still deliver light and heat to surfaces at a rate roughly 600 times greater than that of a desert sun at noon.¹⁵ The tremendous rate of arrival of the flash of light and heat would result in the effusion of black smoke from the fronts of wood houses as paint burned off wood surfaces. Light from the fireball shining through building windows, including those in the Capitol Building and in the House and Senate office

¹⁴There are also a few structures on Capitol Hill that could be considered industrial. The First District electric [?] power generating plant [it's called First District Sub Station on the AAA map] at Sixth and E streets, S.E. is just over 3 miles from the Pentagon.

¹⁵At the Capitol Building itself, 3 miles from the Pentagon, the fireball would be as bright as a thousand suns, delivering about 28 cal/cm² to exposed surfaces, almost three times the thermal fluence deposited at the perimeter of mass fire at Hiroshima.

buildings arrayed around the Capitol, would ignite papers, curtains, light fabrics, and some furniture coverings. Even though the Capitol building is a fire resistant structure and stands in an open space at a distance from other buildings, fires would be ignited in offices and could eventually burn with high intensity. By the time these fires intensified sufficiently to set off emergency sprinkler systems, water pressure from a failing central water system might be too low to extinguish these fires. Thus, even though the Capitol Building is very well constructed to resist fire, large sections of the building would probably suffer heavy damage from fires initiated in the two wings containing offices. The House and Senate office buildings would suffer a much more serious fate. The interiors of these buildings would most likely burn, along with the abutting residential buildings and large old trees that adorn these areas.

In the neighborhood of Capitol Hill, and in all similar in-range neighborhoods in Alexandria, Arlington, and elsewhere, trees and vegetation would be set aflame, and innumerable fires would be ignited in and around buildings. The clothing on people within direct line of sight of the fireball would burst into flames or melt, and areas of skin not covered by clothing would be severely scorched, causing body wounds more severe than third degree burns.

The relatively weak blast wave would knock in windows and doors, and possibly the door frames in wood frame buildings. The exterior walls of brick apartment buildings would be shattered, followed by probable collapse, although the buildings would be left standing. Buildings of heavy construction, such as the monumental buildings on Capitol Hill, would suffer little or no structural damage, but all exterior windows would be

shattered and nonsupporting interior walls and doors would be severely damaged or blown in.

At Union Station, less than 3.5 miles from the Pentagon, the majestic front facade of glass would be blown in, creating razor sharp projectiles that would lacerate or pierce deeply into bodies of those in the open reception areas and in the stylish upper deck restaurants facing the Capitol. Fires would be initiated in the upper decks, as burning restaurant curtains, table cloths, and other combustibles ignited. Trains sitting at loading platforms would, at least initially, suffer little or no damage, as the massive station building would shield them from the fireball light and much of the blast and accompanying winds. There would be no water to fight fires burning in sections of the building that contain combustibles, and areas a mile beyond the building¹⁶ to the north would within tens of minutes be aflame. These burning areas to the north would be part of the great fire that would engulf the city following the detonation, generating heated high winds that would be laden with burning pieces of material. These firebrands, along with noxious smoke and pieces of debris carried by the wind, would be channeled by the surrounding station structure into the north-facing loading platform areas, and would turn this initially safe haven into a blast furnace of death by heat prostration and gas poisoning.

Although blast damage would not be nearly as severe as that closer to the point of detonation, streets would nevertheless be blocked with fallen debris and much burning material would have been dispersed. Due to the

¹⁶ Roughly ninety percent of the time, visibility conditions would result in the deposition of roughly 10 cal/cm^2 from the fireball to a range of four to four and half miles. This fluence would cause many ignitions in areas that would almost certainly then be part of the mass fire that would follow the detonation. Much of the area north of Union Station is lower class residential housing, which is yet more likely to burn due to the associated afflictions of poor garbage control and poor building and area maintenance.

scouring effects of the high winds that would accompany the shock wave, there would be large amounts of dust lofted into the air. There would be fires everywhere. Smoke and dust in the air would create a dense low visibility fog-like environment in the streets, making it difficult or impossible to even read street signs and greatly hampering the ability of individuals and groups to move about.

At this and greater ranges from the detonation point, the source of fire ignitions would not result solely from the tremendous release of thermal energy, which would deposit radiant light and heat on exposed surfaces, causing the simultaneous combustion of many surfaces and structures. Additional ignitions would be caused by the breakup of structures from the blast wave and from accompanying blast winds. This would cause fires by releasing flammable materials (such as gas released by the disruption of gas lines and chemicals and other hazardous materials released by the disruption of industrial processes), by exposing electrical lines and equipment, and by further exposing ignitable surfaces. Such fires are called "blast disruption" fires. Yet more ignitions would be caused by firespread resulting from radiant heat, and from the winds accompanying the blast wave, which would carry burning material (fire brands) which would act as torches on other material.¹⁷ In the immediate minutes after the detonation, a very large number of fires would ignite inside the area three and a half miles from the detonation. (This area, πr^2 , or $3.14 \times (3.5)^2$, would be almost 40 square miles.)¹⁸

¹⁷Clear discussions of thermal-induced ignitions, blast-induced ignitions (disruption fires), and fire spread are: Harold L. Brode and Richard D. Small, *Fire Damage and Strategic Targeting*, PSR Note 567, Contract DNA 001-82-C-0046, Sponsored by Defense Nuclear Agency, Washington D.C. (Los Angeles, California: Pacific-Sierra Research Corp., June 1983), pp. 10-21, and H.L. Brode et al, *Fire Damage to Urban/Industrial Targets*, PSR Report 1936, Contract DNA001-88-C-0055, Prepared for Headquarters Defense Nuclear Agency, Washington D.C. (Los Angeles, California: Pacific-Sierra Research Corp., 25 July 1989), Vol. 1, *Executive Summary*.

¹⁸ However, if the range at which these effects combine to result in the creation of a mass fire

Within tens of minutes after the cataclysmic events associated with the detonation, a momentous mass movement of buoyantly rising fire-heated air would signal the start of a second and distinctly different event -- the development of a "mass" large-area fire of gigantic scale and ferocity. Such a mass fire would increase in intensity within tens of minutes. In a fraction of an hour it would generate ground winds of hurricane force with average air temperatures well above the boiling point of water, producing an environment of remarkable ferocity, destructiveness, and lethality over vast contiguous areas. The uniquely ferocious character of these fires would result from two distinct attributes -- a large simultaneously combusting area, and a simultaneously combusting fuel load typical of that contained in an urban or suburban area.

The first indicator of a mass fire in the target area would be strangely shifting ground winds of growing intensity. (These winds are entirely different from, and unrelated to, the earlier-occurring winds which exert "dynamic pressure" on structures and which accompany the blast wave.) These winds would be caused by the buoyant rise of a vast column of heated air from the fires within the many tens of square miles of target area, much like a gigantic bonfire. As this heated air rose from the fire zone, its movement would create a low pressure region behind it and near the ground. This would then cause cooler air from surrounding ground-regions to be drawn into the fire zone. As the large-scale motion of the rising hot air column intensified, so would the giant pumping action of air from the periphery of the fire zone. The intensifying movement of air from the periphery would manifest itself as ground winds of increasing speed. These

occurred at a fluence of 10 cal/cm^2 , then an area within 4.6 miles of the detonation point would be ignited. Such a mass fire would cover an area of 60 square miles, fifty percent larger than that associated with a fluence of 20 cal/cm^2 .

winds would fan the fires, causing them to increase in intensity and spread. As the fires increased in intensity they would generate still higher volumes of hot rising air which in turn would cause higher speed ground winds. The higher speed winds again would increase the fire spread and burn rate, and the cycle again would cause an intensification of both the fires and the ground winds.

This intensifying air movement could be expected to create ground winds of hurricane force. Such winds would drive the normally near vertical flaming outputs of combusting buildings horizontally towards the ground, filling city streets with hot flames and combusting firebrands, breaking in doors and windows, and causing the fire to jump hundreds of feet to engulf all things that were not yet combusting violently. These extraordinary winds, a physical consequence of the buoyant rise of heated air over vast areas of ground-surface, would transform the targeted area into a gigantic hurricane of fire.

The extraordinarily high air temperatures and wind speeds generated by the fire that would follow a nuclear detonation over a city or suburb is simply a consequence of a vast area simultaneously being on fire. The strikingly unique character and ferocity of such a large-area fire can be readily understood by noting that the driving force behind this phenomenon is the size of area on fire and the volume of buoyantly rising air over such a fire. As the size of the area on fire increased, so would the volume of buoyantly rising air over the fire zone. As the volume of rising air increased, more air would be sucked in from the periphery, generating high-speed winds.¹⁹

¹⁹Imagine that the size of a burning area were increased by a factor of four. The burning area would then cause roughly four times more air to buoyantly rise over the fire area. Although the fire zone had quadrupled in area, the size of its perimeter had only doubled. Since four times more air would be buoyantly rising over the fire zone and the size of the fire perimeter only

The ferocity of such a fire would be further increased because the rate at which a column of air will buoyantly rise is determined by the air temperature. The higher the temperature of the heated air, the faster it will rise. As the size of a mass fire area grows, the rate at which the air above the fire zone rises is determined by the temperature it is heated to by fires. If the ground winds do not increase in direct proportion to the size of the area, then the only way the balance of energy and air flow can be maintained is if the air within the fire zone is heated to higher temperatures. Thus, as the size of the fire zone increases, both the intensity of the winds and magnitude of the air temperature will increase.

Thus, the entire area to 3.5 miles from a detonation at the Pentagon, and quite likely out to 4.5 miles, would, within tens of minutes be engulfed in a mass fire set by the near simultaneous ignitions caused by the deposition of thermal energy, by blast disruption causing structures to break up and flammable material to be released, and by firespread from radiant heat and fire-wind driven flying firebrands -- all of which would cause a very large volume of air to heat and rise. This large volume of rising air would pull in vast amounts of air from the periphery of the fire, which would, like a giant bellows, cause the very numerous fires to coalesce into a single mass fire of extraordinary scale and intensity.

In the neighborhoods out to at least 3.5 miles from the detonation, including those on Capitol Hill, in Alexandria, Arlington, Georgetown, and near Dupont Circle, many buildings would have been set on fire by the thermal flash and been very heavily damaged by the blast wave. Under these

doubled, air must be drawn into the fire zone at twice the speed of that relative to the smaller fire zone. Thus, as the size of area simultaneously on fire increased, so would the winds generated by the area-fire.

conditions, the numerous fires already ignited would quickly spread and intensify, engulfing the whole area in a region of mass fire. Virtually all buildings in these neighborhoods would be destroyed by the unchecked fires that would follow in the hours after the detonation.²⁰

The uniquely ferocious mass fire that would follow a nuclear attack on a city is distinctly different from the large fires that destroyed Chicago in 1871 and San Francisco in 1906. These fires did not occur as large area, or mass, fires, but were instead line fires that burned for days as they swept across the cities driven by winds. Following the 1906 San Francisco earthquake, for instance, a line fire destroyed just over 4 square miles (slightly less than the area destroyed at Hiroshima) during a 72 hour period. At the time, this fire was described as “the greatest fire in the history of the world.”²¹ Only small fractions of a square mile burned at any particular time during the 72 hour period of the fire. Since the area on fire at any time was hundreds of times smaller than the mass fire being considered here, the fire could not generate the high winds and air temperatures that are characteristic of much larger area fires. In addition, the fire propagated quite slowly, making it possible for potential victims to move, or to be moved, before the fire reached them.²²

²⁰use? In the case of the Capitol Building itself, its unusual circumstances might save it from being completely destroyed, at least in this example. This would largely be a result of it being a very large fire resistant building placed in a large open area away from the other buildings that would burn. However, as noted above, large sections of the building would still probably suffer very heavy damage from fires and from blast effects.

²¹Area destroyed and quotation: U.S. Geological Survey, Department of the Interior, *The San Francisco Earthquake and Fire of April 18, 1906 and Their Effects on Structures and Structural Materials*, U.S. House of Representatives, 60th Congress, 1st Session, Document No. 719 (Washington, D.C.: Government Printing Office, 1907), p. 138. Also see the scholarly and handsomely produced *Denial of Disaster, The Untold Story and Photographs of the San Francisco Earthquake and Fire of 1906* (San Francisco: Cameron and Co., 1989), by Gladys Hansen and Emmet Condon. Condon had been chief of the San Francisco Fire Department.

²²This is not to say that such line fires do not generate high winds and temperatures, only that they are not as intense as those of a mass fire. In the San Francisco fire following the earthquake, Frank Soulé, a prominent engineer reported, “At first there was little or no wind to fan the flames, but the great heat soon drew in a current of air which continually increased, and varying from one point to another, swept the flames first in this direction and then in that. By

Other examples of highly destructive line fires that should not be confused with area fires are the London fire of 1666, the great forest fires in the midwestern United States of 1871 (known as the "Black Year"), and the recent suburban fire that raged in the Oakland hills in 1991.²³

In striking contrast to these line fires are the fundamentally different mass fires that were intentionally created by conventional incendiary raids or as an inevitable byproduct of atomic weapons attacks by the allies during World War II. These fires include those that destroyed Hamburg, Dresden, Tokyo, Hiroshima, and Nagasaki. For example, the mass large-area fire created by allied incendiary raids at Hamburg burned out the city in 3 to 6 hours. Very well documented accounts describe wind speeds of hurricane force within the city, and calculations indicate that air temperatures were hundreds of degrees Fahrenheit above the temperature of boiling water.²⁴ A mass fire resulting from a modern nuclear weapon could be expected to burn out an urban or suburban area of a considerably larger size in a similar amount of time. The unique feature of the mass fire, simultaneous combustion over a large area, distinguishes it in fundamental ways from large propagating line fires of past experience.²⁵

Wednesday noon [about 7 hours after the earthquake] the fire had consumed nearly a square mile of the city...." (U.S. Geological Survey, *The San Francisco Earthquake and Fire*, p. 137). Another engineer judged the temperature as follows: "All things considered, I am inclined to think that temperatures considerably in excess of 2,000° F. were not at all uncommon in the San Francisco fire, although there were manifestly, in the burned area, places where no such temperature was reached" (U.S. Geological Survey, *The San Francisco Earthquake and Fire*, p. 69).

²³On the great [forest] fires in the United States, see Stephen J. Pyne, *Fire in America: A Cultural History of Wildland and Rural Fire* (Princeton: Princeton University Press, 1992), pp. 199-200. [check that the 1871 fires were mainly forest or rural or whatever.]

²⁴Bond, USSBS.

²⁵[maybe use. for now, a fn.] Mass fires caused by higher-yield nuclear weapons could occur on a scale unprecedented in history. The area set on fire would depend to a great extent on the yield of the weapon. At Hiroshima, for instance, a 12.5 kiloton bomb set aflame an area about 4.4 square miles, with a diameter of about 2.3 miles. A more modern weapon, such as a 300 kiloton bomb typical of those carried on the MX missile or the Minuteman IIIA, could set afire an area of 40 to 60 square miles, with a diameter of approximately 7 to 9 miles. A mass fire of this

Fire environments created by large area fires are fundamentally more violent, ferocious, and destructive than fires of smaller scale, and they are far less affected by external weather conditions. These fires would not be substantially altered by seasonal and daily weather conditions because their dynamics are determined by the intense hydrodynamic flows generated by the vast releases of energy from combustion and the inevitable buoyant rise of air over the fire zone. In other words, a nuclear detonation near an urban or suburban area would cause numerous ignitions -- from thermal energy directly deposited on surfaces, from blast disruption, and from fire spread -- which would sufficiently heat the air to cause a giant hydrodynamic pumping of air from the periphery toward the center, leading to a coalescing of a mass fire. The effects of the detonation would create their own exceptionally intense environment, causing many of the otherwise expected variations to cancel out, and leading to a mass fire.

This is not to deny uncertainties in the damage ranges associated with the initiation and spread of mass fires, nor is it to deny that variations in environmental conditions could contribute to variation in the expected range of mass fire. The precise location of the perimeter of mass fire following a nuclear attack is uncertain; whether it would occur at 10 cal/cm², as it did at Hiroshima, or at 15 or 20 cal/cm², and how it might be affected by topography or the weather is also uncertain. (For this reason, I described a mass fire at 20 cal/cm², occurring at a range of 3.5 miles from the detonation. If the perimeter of mass fire from the detonation of a 300 kiloton nuclear weapon

intensity and scale, with a diameter of 7 miles or greater, has not been observed in human history. However, the giant pumping action from buoyantly rising air is a phenomenon that follows from the basic physics of fire-heating and the laws of compressible fluid flow (called the science of "fluid dynamics"). (A yet larger ten megaton weapon, which is of a yield close to that of the now retired Titan II missile, could set afire an area of 700 to 1200 square miles -- a circular area of diameter roughly 30 to 40 miles.)

were to occur at 10 cal/cm², as at Hiroshima, then the mass fire would burn out an area extending 4.6 miles from the detonation, that is, an area with a diameter of over 9 miles.)

However, two points should be kept in mind. First, the uncertainties in the range of damage associated with fire are not greater than the uncertainties associated with blast. Indeed, uncertainties in the damage range associated with the initiation and development of mass fires are comparable to uncertainties in damage range associated with blast. As with blast, these variations can be estimated and modeled.²⁶ For blast damage, the range at which a 15 pound per square inch overpressure occurs is uncertain to plus or minus 15 percent.²⁷ In addition, the likelihood that a building or structure subjected to a specific blast overpressure would be damaged to the prescribed level will vary with accidents of construction details, orientation of the structure relative to the arriving blast wave, whether or not the structure is on the windward or leeward side of a hill, and whether or not the structure is in the pressure shadow of other structures.

²⁶[can I find a quote that directly says the uncertainties in range for fire are not greater than for blast?] According to Brode and Small, in a study estimating damage ranges from both thermal and blast effects, and taking into account uncertainties due to weather conditions, civil defense measures, and uncertainties or variations in atmospheric transmission and target vulnerabilities, "Despite the uncertainties, fire damage can be predicted with useful consistency; such predictions could become as reliable as corresponding blast damage predictions. The inclusion of fire in the damage prediction methodology would improve and extend current damage assessments" (Harold L. Brode and Richard D. Small, *Fire Damage and Strategic Targeting*, PSR Note 567, Contract DNA 001-82-C-0046, Sponsored by Defense Nuclear Agency, Washington D.C. [Los Angeles, California: Pacific-Sierra Research Corp., June 1983], p. 32); their analysis shows that for initial fire starts, including both blast-induced and thermal-induced ignitions, "[o]nly moderate sensitivity to attenuation of the thermal radiation...occurs, since inclusion of blast-induced ignitions lessens the influence of those parameters (i.e., short visibility lengths of high levels of absorption by cloud decks). Similarly, only moderate changes result from variation of the atmospheric transmissivity form" (p. 19)...Plus Eden interview w. R.

²⁷H.L. Brode, *Review of Nuclear Test Peak-Overpressure Height-of-Burst Data*, PSR Note 353, [contract number for whom?] (Santa Monica or Los Angeles, California: Pacific-Sierra Research Corp., November 1981), p. [get from Ted].

Second, for higher yield nuclear weapons, in the 100 kiloton range or above, under almost all conditions that could influence the situation, such as weather, the range of damage for thermal effects extends far beyond the perimeter of anticipated blast damage for many targeted structures.²⁸

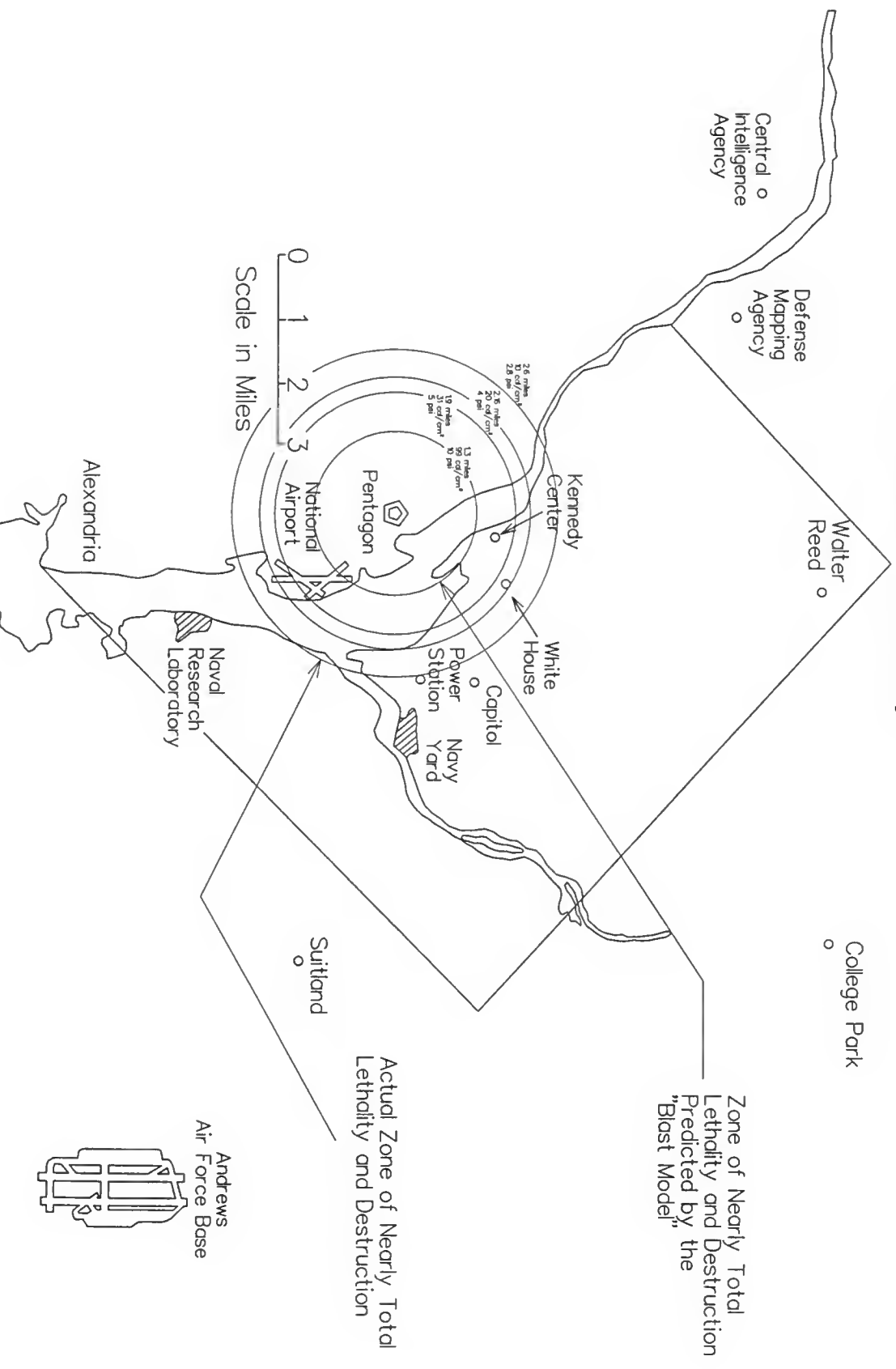
At close-in distances (one and a half to two miles), the flash from the fireball from a 300 kiloton detonation would set fires under virtually all weather conditions. For example, a reduction in visibility from 10 miles to less than 2 miles (see map), from the visibility of a relatively clear day to a day in which visibility would be so poor that from the elevated Metro station at National Airport, there would be no chance of observing the Washington Monument, the Jefferson Memorial, or the Capitol Building, the thermal fluence on aircraft at National Airport, 1.6 miles from the detonation at the Pentagon, would be reduced from 111 cal/cm² to 54 cal/cm². Even under these circumstances, the flash from the detonation would still be sufficient to destroy these aircraft by warping their metal surfaces and setting them on fire. Even if the visibility were only about a half mile, a devastatingly destructive fluence of 35 cal/cm² would still be delivered to the aircraft.²⁹

²⁸Based on a different analysis from that used in this text, Brode and Small arrive at a similar conclusion: "In general, fire damage radii exceed those for moderate blast damage....In addition to greater damage radii, fire may cause more complete and permanent damage. A structure only moderately damaged by blast may be gutted and rendered useless by fire. Similarly, building contents may survive the blast but be destroyed by the fires....Both blast and fire will damage targets (industrial sites) and nontargets (apartments); but fire will generally go farther and cause more complete damage to both" (pp. 32,33). Significantly contributing to the range of damage from fire is firespread. Brode and Small use a conservative estimate "that the probability of fire damage at any radius is doubled when spread is included" (p. 20). Harold L. Brode and Richard D. Small, *Fire Damage and Strategic Targeting*, PSR Note 567, Contract DNA 001-82-C-0046, Sponsored by Defense Nuclear Agency, Washington D.C. (Los Angeles, California: Pacific-Sierra Research Corp., June 1983).

²⁹ The attenuation levels due to visibility changes used here are almost certainly excessive, since low visibility conditions often are due to fog and/or particulates that are mostly near the ground. The fireball would initially have a height of nearly a kilometer and would be rising off the ground as it radiated. As a result, a very large fraction of the radiant energy from the fireball would not be attenuated, as most of its path would be through clear air at higher altitudes. Thus, the effects of changes in visibility used here are maximal.

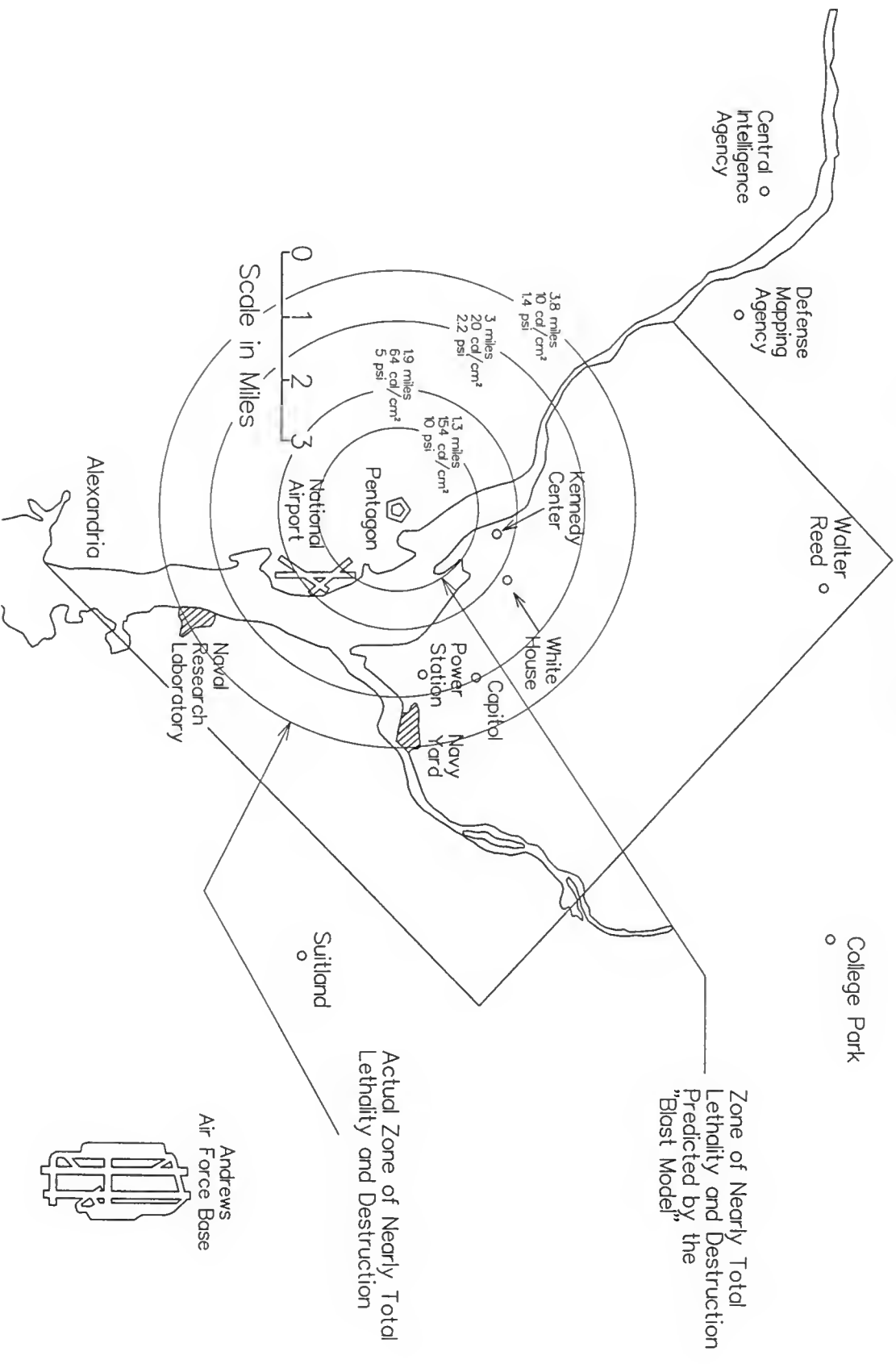
Effects of Detonation at the Pentagon of 300kt Nuclear Weapon Near—Surface Burst

2 Miles Visibility



Effects of Detonation at the Pentagon of 300kt Nuclear Weapon Near—Surface Burst

5 Miles Visibility



Even at greater ranges, reduced visibility conditions would not stop the initiation and development of a very large area fire. For example, a reduction in visibility from 10 miles to 5, from the visibility of a relatively clear day to the visibility of a misty rainy day, would reduce the thermal fluence at three and a half miles from 20 cal/cm² to about 13 cal/cm², still enough fluence to set many objects on fires (see map). Thermal fluence of 20 cal/cm² would still occur at about 3 miles from the detonation, that is, at the Capitol Building, a reduced range of only 17 percent, and still double the thermal fluence at the edge of mass fire at Hiroshima. A reduction in visibility to about 3 miles would reduce the thermal fluence at the Capitol to about 10 cal/cm². Under these conditions, it would be sufficiently misty or foggy that it would not be possible to see the Capitol Building from the Lincoln Memorial.³⁰

If the ground were snow covered, vegetation covered by snow would

³⁰[Is Ted sure that at 3 miles you can't see the Capitol Building from the Lincoln Memorial?] Based on a decade of hourly weather observations at National Airport, visibility of 10 miles or greater occurs 64 percent of the time, and visibility of 5 to 10 miles occurs 26 percent of the time. In other words, visibility of 5 miles or greater occurs 90 percent of the time, or the equivalent of 328 days per year. Visibility of 3 miles or greater occurs 97 percent of the year, and, of course, visibility of less than 3 miles occurs 3 percent of the year. Visibility of less than 2 miles occurs about 1.5 percent of the year, and visibility of less than 1 mile occurs about 1 percent of the year. See Federal Climate Complex Ashville, U.S. Navy-U.S. Air Force, Department of Commerce, *International Station Meteorological Climate Survey*, prepared under authority of Commander, Naval Oceanography Command, Version 1.0, October, 1990. This same survey lists similar data for many observations points in the world, including, for example, Moscow. I want to thank Benjamin Olding for finding this data and putting it in an easily comprehensible form.

Later, I want to work into the text the following from Ted (which accompanies the diagrams Ted sent): For 300 kt warhead near-surface burst:
5 psi range is roughly at 1.9 miles
the 10 cal/cmsq range for 1 mile visibility is roughly 2 miles
the 10 cal/cmsq range for 2 mile visibility is 2.5 miles
the 10 cal/cmsq range for 3 mile visibility is 3 miles
Hence, 1.7 times the area is destroyed if 10 cal/cmsq is the damage criterion rather than 5 psi and the visibility is 2 miles. 2.5 times the area is destroyed if 10 cal/cmsq is the damage criterion rather than 5 psi and the visibility is 3 miles.
If 20 cal/cmsq versus 5 psi is the criterion, then the 20 cal/cmsq and 5 psi range coincide when the visibility is 1.5 miles. For 2 miles visibility, the 20 cal/cmsq range is 2.14 miles, resulting in an area 25% larger subject to 20 cal/cmsq or larger versus 5 psi or larger criterion. For 3 miles visibility, the area is greater than 1.7 [restate this].

not be initially ignited, but light and heat from the fireball would be reflected by the snow, roughly doubling the amount of light entering building windows. Further, during periods of cold weather when snow cover would be a factor, the warm interiors of buildings have very low relative humidities, greatly increasing the likelihood of ignitions. The mass fire set at Dresden in February, 1945 with non-nuclear incendiary weapons occurred under a heavy snow cover.³¹

On cloudy days, if a nuclear weapon were detonated below the cloud cover, the light shining into buildings would also be intensified by a factor of about two, as light reflected from the cloud cover shined into the interiors of buildings. When there is both snow and cloud cover, light reflected by both the snow cover and cloud bottoms could intensify the fire initiating light flash from the fireball by a factor of roughly four.

Only periods of extremely intense rain, or of heavy ground fog, or if detonations occurred at altitudes above cloud cover, would lead to situations where the size of the fire zone was comparable to that of the zone of heavy destruction by blast. However, such weather conditions are rare and can be, and could have been, accounted for. The likelihood of such weather is known by location and time of year. In addition, real-time or near real-time weather data has been available on a global basis for decades. In fact, the widely accepted public data on the accuracy of ballistic missiles indicates that weather update data has almost certainly been a part of missile attack targeting for many years.³²

³¹check snow cover. Bond, maybe Sherry or Shaffer or Brit. history, or Davis on Spaatz.

³² This observation is established as follows. An ICBM warhead takes about 8 to 10 seconds to descend from about 15 kilometers to the ground. Under typical continental weather conditions, an average wind speed over a target of 15 to 20 knots is quite common. If not accounted for, this wind would translate the impact point of an arriving warhead by 8 to 10 meters during each second below 15 kilometers -- resulting in a miss of 80 to 100 meters. However, the widely

In sum, due to the great diversity of mechanisms leading to fire initiation and spread, a mass fire with a radius of at least 3.5 miles would ensue in all but the most extreme of weather conditions and in spite of variability in the weather. Once this fire intensified, it would not be much affected by external weather conditions, as the tens of millions of megawatts of power released by combustion would create a local environment on the ground so intense that it would be completely governed by the dynamics of the fire. The fire would generate its own extremely intense winds, air temperatures would be so high that wet surfaces would quickly dry, and the relative humidity within the fire zone would be very low. Thus, such a fire, unlike those of smaller scale, would only be weakly influenced by details of the external weather conditions.

The above discussion is consistent with the understanding of a small number of scientists who have worked extensively on understanding the effects of nuclear weapons, including the thermal effects of those weapons. (However, as we shall see in some detail below, this is not an understanding widely accepted within the nuclear targeting community.³³)

These scientists include Theodore A. Postol, trained as a physicist and nuclear engineer at the Massachusetts Institute of Technology and now a tenured professor there, and the physicist Harold Brode, who has been even more deeply involved in analyzing nuclear weapons effects. Brode, whose entire career has been devoted to the study of nuclear weapons effects is,

quoted accuracy of missiles like the MX and Trident II is about 100 meters. Such an operational accuracy would not be possible if the miss errors from weather alone is roughly 100 meters. Thus, either the widely accepted accuracy figures are incorrect, or the targeting process incorporates updated weather data so that winds can be accounted for over the target.

³³In addition to those discussed below, I have interviewed a half dozen others who would agree with the general thrust of this analysis. [See separate doc: halfdoz.]

without doubt, one of the country's pre-eminent experts on those effects.³⁴ About fifteen years ago, along with a team of scientists at the consulting firm Pacific Sierra Research Corporation, Brode began investigating the possibility of incorporating thermal effects into damage prediction for nuclear targeting. This work was done under contract for the Defense Nuclear Agency, the government agency responsible for understanding the effects of nuclear weapons. By the late 1980s, Brode and his colleagues thought they had developed an analytical basis for predicting the damage caused by the thermal effects of nuclear weapons. However, in early 1992, the federal funding for the on-going studies by Brode and his associates was canceled, and no further work has been undertaken since. Had the U.S. government accepted the work of Brode and his colleagues, it would have portended a major change in how the government has calculated damage caused by nuclear weapons for the past half century.

We can see how great the changes would have been by comparing the differences in damage predicted by the above account, which includes both blast and thermal effects, with the method used by the U.S. government to predict damage from blast effects only. For many targets (although not all), the differences are very great. (For a detailed comparison of damage predicted from blast effects and damage predicted from a combination of blast and thermal effects, see Appendix A, "Table of Nuclear Effects for 300 kt Nuclear Weapon: A Comparison of Damage Predicted by the *Physical Vulnerability Handbook* and Damage and Effects Not Predicted by the *Handbook*," by Theodore Postol.)

³⁴See, for example, Harold L. Brode, "Review of Nuclear Weapons Effects," in Emilio Segrè, ed., J. Robb Grover and H. Pierre Noyes, associate eds., *Annual Review of Nuclear Science*, Vol. 18 (Palo Alto, California: Annual Reviews, 1968), pp. 153-202.

To see the differences in damage prediction, let us return to an imaginary 300 kiloton nuclear weapon detonated in a near surface burst at the Pentagon and compare the damage and effects already described with the damage predicted by the U.S. government to a number of structures in the Washington area.

The government's method for predicting damage to structures, installations, and equipment is published by the U.S. Defense Intelligence Agency as the *Physical Vulnerability Handbook--Nuclear Weapons*. It has been published in a number of editions, from 1954 to, most recently, 1992.³⁵ The *Physical Vulnerability Handbook* is based on a sophisticated system that characterizes types of structures in terms of their physical vulnerability to blast effects. In the handbook, structures are characterized in terms of "physical vulnerability numbers," or, synonymously, "vulnerability numbers" or "VNs" at specified damage levels.³⁶ (Physical vulnerability is also synonymous with "target hardness." The strength, or hardness, of a structure corresponds to the blast pressure at which a structure will sustain a

³⁵I draw on an unclassified edition of the handbook, formerly classified as "confidential," from the late 1960s and early 1970s (see below). The handbooks, in order of publication, are: Physical Vulnerability Division, Directorate for Intelligence, Headquarters United States Air Force, *Target Analysis for Atomic Weapons*, AF-628202 [chk], PV TM-14, 30 June 1954. This was succeeded by Physical Vulnerability Division, Director for Targets, Assistant Chief of Staff, Intelligence, Headquarters United States Air Force, *Nuclear Weapons Employment Handbook* (U), AFM 200-8, 1 May 1958 (both above cited in Binniger, et al, *Mathematical Background*, November 1974). The next editions were: *Nuclear Weapons Employment Handbook*, AFM 200-8, (Washington, D.C.: Physical Vulnerability Branch, Targets Division, Air Force Intelligence Center, Assistant Chief of Staff, Intelligence, Headquarters United States Air Force, 1 September 1961); (U) *Physical Vulnerability Handbook -- Nuclear Weapons* PC 550/1-2-63 (Washington, D.C.: Defense Intelligence Agency Production Center, 1 September 1963); and Defense Intelligence Agency, *Physical Vulnerability Handbook--Nuclear Weapons* AP-550-1-2-69-INT (Washington, D.C.: Defense Intelligence Agency, 1 June 1969, with change 1 [1 September 1972] and change 2 [28 January 1974]). In 1992 a new edition was published: Defense Intelligence Agency, *Physical Vulnerability Handbook for Nuclear Weapons (U)*, Defense Intelligence Reference Series, prepared by the Target Intelligence Division, Directorate for Research, Defense Intelligence Agency, OGA-2800-23-92, January 1992.

³⁶explain that it's really VNTK, numbers and letter codes representing overpressure and also sensitivity to peak overpressure or dynamic pressure and duration. see below, blah blah.

predefined level of damage.) Physical vulnerability numbers correspond to measures of blast overpressure in pounds per square inch (psi) for specified levels of damage. This characterization of physical vulnerability is *always* stated in terms of level, or kind, of damage -- for example, severe, moderate, or light -- that the structure would be expected to sustain at a given overpressure.³⁷ Thus, a monumental building, such as the U.S. Capitol Building, might be predicted to sustain severe damage when subjected to blast overpressure of approximately 20 psi. As noted above, the government's handbook does not actually list overpressure but rather a code corresponding to overpressure; this structure would be characterized as a 18Q8 target.³⁸ The same structure would be predicted to sustain moderate damage when subjected to overpressure of approximately 15 psi; at this level of damage, the *same* structure would be characterized as a 15Q5 target.

Despite the sophistication of the system, because only blast effects are taken into account, for many targets the predicted damage is vastly understated. For example, one target listed in the *Physical Vulnerability Handbook* is a surfaced submarine with a vulnerability number of 28P0; at this rating, according to the government's method of calculating damage, the submarine would sustain "Slight loss of ability to achieve top speed or to maneuver, because of equipment damage or personnel casualties."³⁹ The submarine would be subjected to 185 psi, and would be .35 miles from the

³⁷Briefly, structures sustain "severe damage" when they have to be completely rebuilt; structures sustain "moderate damage" when major repair, but not replacement, is required. According to the government's handbook, severe structural damage requires "that degree of structural damage to a building which precludes further use of the building for the purpose intended without essentially complete reconstruction or replacement. A building sustaining severe structural damage requires extensive repair before it can be used for any purpose." (PVH, p. I-3). Moderate structural damage is "that degree of structural damage to principal load-bearing members...of a building which precludes effective use of the building for the purpose intended until major repairs are made." (PVH, p. I-3.)

³⁸very brief explanation of VNTK code.

³⁹PVH, p. xx.

detonation. (Hypothetically, for illustrative purposes, the submarine would be approximately located in the Boundary Channel by the Pentagon.) Not noted in the *Handbook*, but consistent with its methodology, is that the accompanying winds would be 2,000 miles per hour, generating wind-forces more than 3,000 times greater than hurricane force.⁴⁰ The blast wave would be strong enough to loft 50 foot diameter boulders weighing 9 million pounds, about the weight of many modern submarines. One might wonder whether these effects would lead only to "slight loss of ability," but in any case, the damage is clearly understated when we consider that at this range, the fireball would be 80,000 times brighter than a desert sun at noon, ultimately delivering a whopping thermal fluence on the surface of the submarine of 2,617 cal/cm².

Another target of interest to military planners is the aircraft carrier. This class of target is listed with a vulnerability number of 11P0 for very light damage, which would place it at about 1.45 miles range from the Pentagon (hypothetically, just off Gravelly Point north of National Airport). The expected state of damage predicted by the *Physical Vulnerability Handbook* is "Slight loss of ships [chk] ability to achieve top speed or to maneuver because of equipment damage or personnel casualties."⁴¹ At this range the thermal flash would be more than 4,000 times brighter than a desert sun at noon, the blast overpressure would be over 8 psi, and the winds would be over 250 miles per hour, generating wind-forces more than 15 times greater than those

⁴⁰As noted above, hurricane forces are here defined as 70 mph winds. The wind-forces are due to the motion of compressed air associated with the propagating shock. The air density and wind-speed immediately behind the leading edge of the shock can readily be determined from the equation of state of air, and the Rankine-Hugoniot conditions -- which are a result of mass, energy and momentum conservation. For a derivation of equations for the air density and speed of the air behind an ideal shock front, see Glasstone and Dolan, *Effects of Nuclear Weapons* (1977), pp. 96-99.

⁴¹PVH, p. xx.

of hurricane force.

Again, even the damage from blast seems understated; the blast wave would severely damage or remove all antennas on the superstructure of the ship, and it would also do very serious damage to the superstructure itself. However, of much greater importance would be the effects of thermal radiation and the interaction of thermal effects and blast effects. Fires would first be started by the light flash, and would be followed, 7 seconds later, by the arrival of the blast wave and winds which would overturn and break up fuel-laden aircraft. Under these conditions, it is hard to imagine that the ship could be other than a floating inferno.

A third target of interest to military planners is aircraft. According to the *Physical Vulnerability Handbook*, light fighter and bomber aircraft located 1.6 miles from a detonation and oriented toward it ("nose-on") would sustain only "light damage." The *Handbook* describes damage to these aircraft as follows: "Light damage to aircraft consisting of structural failure of small control surfaces, bomb bay and wheel doors, fuselage skin damage and damage due to flying debris. *Requires one to four hours repair but may permit limited flight* [emphasis added]."⁴² The government's handbook bases this prediction of damage on the expected blast forces on the aircraft. At this distance, the blast wave from a detonation at the Pentagon would have a peak overpressure of a little less than 7 psi. (This blast wave would be sufficiently intense to cause the complete collapse and disintegration of typical two story wood frame and brick buildings.) The winds accompanying the blast would be a little less than 220 miles per hour, generating wind forces more than ten

⁴²PVH, p. xxx. I am using the *Physical Vulnerability Handbook* assignment of a vulnerability number of 10P0 for "light damage" to nose-on oriented light fighters and bombers. The aircraft are further identified as MIG 15, MIG-17, and YAK-25.

times greater than those of hurricane force. Given that aircraft routinely fly nose-on into winds of several hundreds of miles per hour, we can see how the *Physical Vulnerability Handbook* might arrive at such an expectation of damage.

However, when thermal and other effects are considered, "light damage" seems highly understated. As noted above, at a range of 1.6 miles, which would place the aircraft on the north side of National Airport, the light flash from the fireball would be more than three thousand times brighter than a desert sun at noon and the thermal fluence would be 111 cal/cm². This would be more than sufficient to melt and warp aluminum surfaces on the aircraft, causing control surfaces and other components to jam and to be inoperable. Parts of the interior of the aircraft would catch fire, as would the tires of the aircraft and fuel hoses. In addition, winds associated with the blast wave would lift and overturn planes, smashing them to pieces, as the planes were carried along with other flying objecting that would accompany the shock.

All of these targets would be deep within the perimeter of mass fire. Let us move farther away from the detonation. As noted above, all the built-up areas of Capitol Hill would be engulfed in a mass fire, extinguishing all life, and destroying all large and small buildings and residences. The only buildings that might not suffer complete destruction by fire might be the Capitol and some monumental buildings on the Mall. Some of these buildings could be spared from complete or extensive fire damage because they have few windows through which fires could be ignited by light from the fireball. In addition, since there are large open spaces between these buildings and areas that would suffer complete destruction by fire, it is

possible, but by no means assured, that they might also be spared from firespread.

According to the methods used in the *Physical Vulnerability Handbook*, for the 300 kiloton detonation described earlier, severe damage could only be expected against these buildings if they were at a range .87 miles or less from the detonation, and moderate damage could only be expected at 1.06 miles. At the range of severe damage, .87 miles, the blast wave from the explosion would have a peak overpressure of slightly over 20 psi. The blast wave would be accompanied by 525 mile per hour winds, which would generate wind forces on the buildings almost 100 times those of hurricane-force winds. At the range for moderate damage, 1.06 miles, the environment would be less intense, but hardly benign. The blast overpressure would be about 15 psi and the accompanying winds would achieve speeds of 400 miles per hour. These winds would still create forces 50 times that of hurricane force.

Not noted or relevant in the calculations of damage predicted by the *Physical Vulnerability Handbook* is that at a range of .87 miles, the fireball from the detonation would also deliver about 400 cal/cm² to surfaces, and would appear more than 12,000 times brighter than a desert sun at noon. This rate of thermal heating from the fireball would be so intense that it could cause a thin layer of the concrete surfaces on the buildings to explosively disintegrate, and could ignite virtually any combustible piece of material. At a range of 1.06 miles, the thermal flash would be more than 8,000 times brighter than a desert sun at noon, and the thermal fluence deposited on surfaces would be 266 cal/cm².⁴³

⁴³ There is complex set of interactions between fireball light and materials in a target area that cannot simply described in terms of whether a material is actually ignited. For example,

What level of damage would the *Physical Vulnerability Handbook* predict for the buildings on Capitol Hill, approximately 3 miles from the Pentagon? At this range, the blast overpressure would be about 2.2 psi, and would be accompanied by 75 mile per hour winds, about that of hurricane force. These forces would not meet the government's criteria to achieve severe or moderate damage. (The *Physical Vulnerability Handbook* does not list "light damage" for buildings, presumably because such damage would not be severe enough to meet military planning criteria.) Although for U.S. government planning purposes, the monumental buildings of Capitol Hill would not meet criteria for severe or moderate damage, when thermal effects are taken into account in the prediction of damage, the damage would be severe indeed.

As we have seen, fires would be ignited over vast regions of the target area. When visibility is ten miles or more, an area of 30 to 50 square miles in size would be on fire at the same time. If visibility were 5 miles or greater, a condition that exists 90 percent of the time in the Washington area, an area of 25 to 40 square miles would simultaneously burn. Even if the visibility were below 2 miles, which occurs about 1.5 percent of the time in the Washington area, an area of 12 to 15 square miles would be destroyed. This is two to three times the area destroyed in the great World War II raid on Hamburg.⁴⁴

some materials may violently emit large amounts of black smoke. The resulting pall of smoke could then shield the surface of the material from enough fireball light to prevent its ignition. Such details of the interaction between the light of the fireball and target material are, however, irrelevant to the issues being examined here. So many materials would be set on fire by the light-flash from the nuclear detonation that all other combustible materials would shortly be involved in the mass fire that would follow.

⁴⁴ The largest single area fire that was set during raids on Hamburg between July and August of 1943 occurred on the night of 27/28 July 1943. Although numerous small area fires resulted over a 17 square mile area, the most striking "success" of the attacks was achieved when a single contiguous area of 5.1 square miles was set on fire. This fire generated hurricane force winds in the streets and average air temperatures of at least 400-500 degree F. Between 60,000 and 100,000 people died that night in this fire. See Horatio Bond, "The Fire Attacks on German Cities," in Horatio Bond, ed., *Fire and the Air War* (Boston or New York [check]: National Fire

Average air temperatures in the areas on fire after the attack would be well above the boiling point of water, winds generated by the fire would be of hurricane force, and the fire would burn at this intensity for three to six hours. Following the burnout of the fire, the pavement on streets be sufficiently hot that even tracked vehicles could not pass over it for days, and building materials would be so hot that buried unburned material from collapsed buildings could burst into flames if exposed to air weeks after the fire.

Those who might take shelter in basements of strongly constructed buildings would be either poisoned by carbon monoxide that would seep into shelters, or roasted in the extreme oven-like conditions created by the fire-heated concrete ceilings of their shelters. Those who sought to escape through the streets, would be incinerated by the hurricane force fire brand and flame-laden fire-winds. Even those who could find shelter in lower level sub-basements of massive buildings would likely die of eventual heat prostration, poisoning from fire-generated gases, and lack of water. For all effective purposes, the fire would eliminate all human life in the fire-zone.

Protection Association, 1946), pp. 76-97.

Table of Nuclear Effects for 300kt Nuclear Weapon:
A Selective Comparison of Damage Predicted by the *Physical Vulnerability Handbook*^a and Damage and Effects Not Predicted by the *Handbook*^a

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PVH ^a Descriptions of Targets	VNTK ^b	Peak Over- pressure (psi)	Range (miles) ^c	Thermal Fluence ^d (cal/cm ²)	Wind Speed ^e (mph)	PVH ^a Damage Assessments	Notes on Damage & Effects Not Considered in PVH ^a
							From Ground Zero to range of approx. 3.5 miles: area entirely engulfed in mass fire, with thermal fluence at 20 cal/cm ² , temperatures reaching xxx and blah blah blah blah
Runways (p. I-17)	46P0	4920.43	0.11	25529.0	10721.7	Destruction within crater; cracking and displacement beyond crater	
Surfaced submarines (p. I-20)	28P0	184.85	0.35	2616.7	1991.4	Slight loss of ability to achieve top speed and/or to maneuver normally, because of equipment damage or personnel casualties	Blast wave winds strong ^f enough to loft 50 ft diameter boulders weighing 9 million pounds, about the weight of many modern submarines
Surfaced submarines (p. I-20)	27P0	154.05	0.37	2304.1	1802.7	Slight reduction of maximum safe diving depth but can submerge in a controlled manner	Blast wave winds strong ^f enough to loft 40 ft diameter boulders weighing 4 million pounds, about the weight of many modern diesel-electric and some nuclear submarines. Blast wind temperature ^g reaches about 1000 deg F
Corrugated steel igloos in ammunition depots (p. I-15)	27P2	134.93	0.39	2100.5	1675.3	Arch collapsed; moderate to severe damage to contents	
Surfaced submarines (p. I-20)	23P0	74.29	0.48	1383.6	1189.6	Slight reduction in weapon-delivery efficiency due to equipment or topside structural damage, or to personnel casualties	Blast wave winds strong ^f enough to loft 13 ft diameter boulders weighing 160,000 pounds
Locomotives (p. I-13)	21Q5	50.51	0.55	1038.1	940.2	Forcefully derailed or overturned	

**Table of Nuclear Effects for 300kt Nuclear Weapon:
A Comparison of Damage Predicted by the *Physical
Vulnerability Handbook*^a and Damage and Effects Not
Predicted by the *Handbook*^a**

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PVH ^a Descriptions of Targets	VNTK ^b	Peak Over- pressure (psi)	Range (miles) ^c	Thermal Fluence ^d (cal/cm ²)	Wind Speed ^e (mph)	PVH ^a Damage Assessments	Notes on Damage & Effects Not Considered in PVH ^a
Suspension bridges with masonry towers (p. I-14)	22Q9	43.04	0.60	869.7	849.4	Sufficient distortion of at least one cable tower to cause collapse of at least the principal span.	Blast wave winds strong ^f enough to loft 5.5 ft diameter boulders weighing 11,000 pounds
BEER CAN, DOG HOUSE and HEN HOUSE fixed guidance radars (p. I-19)	19P2	31.38	0.71	612.6	689.8	Severe damage to control buildings	Blast winds heated ^g by more than 200 deg F above ambient temperature due to sudden compression of air
Steel Floating Dry Docks (p. I-21)	16P0	20.74	0.89	385.8	515.8	Deformation of sidewalls and overturning of cranes	Blast wave winds strong ^f enough to loft 1.5 ft diameter boulders weighing 200 pounds
Rail mobile missile car, with missile erect and fully loaded (ICBM type) (p. I-18)	17Q7	19.19	0.92	353.7	487.5	Car overturned and missile crushed	
2-10 story steel framed buildings of earthquake resistant design (p. I-3)	17Q8	17.54	0.97	319.6	455.9	Moderate structural damage to principal load- carrying members of a building which precludes effective use of the building for the purpose intended until major repairs are made	Fireball momentarily ^h delivers light and heat at about 10,000 times that of a desert sun at noon
Ballistic liquid fueled missile erect and fully loaded, soft sites; IRBM or ICBM types (p. I-18)	17Q9-18Q9	15.6-19	.9-1	280-349	417-483	Missile overturned and destroyed	Ground surfaces ⁱ explosively blow off from sudden heating by fireball, lifting superheated dust to heights of hundreds
Nuclear Materials: uranium feed materials refining buildings; U-235 production gaseous diffusion buildings; plutonium production reactor buildings; weapons fabrication buildings (p. I-9)	16Q7	15.77	1.03	283.5	420.8	Severe structural damage to buildings which precludes further use for the purpose intended without essentially complete reconstruction or replacement	Blast wave winds strong ^f enough to loft boulders weighing 50 pounds

**Table of Nuclear Effects for 300kt Nuclear Weapon:
A Comparison of Damage Predicted by the *Physical
Vulnerability Handbook*^a and Damage and Effects Not
Predicted by the *Handbook*^a**

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PVH ^a Descriptions of Targets	VNTK ^b	Peak Over- pressure (psi)	Range (miles) ^c	Thermal Fluence ^d (cal/cm ²)	Wind Speed ^e (mph)	PVH ^a Damage Assessments	Notes on Damage & Effects Not Considered in PVH ^a
POL dumps: 5 gallon cans, full (p. 1-15)	16Q8	14.42	1.08	256.4	393.0	Thrown forcibly, damage resulting in loss of contents	
		13.7	1.11	242	378		Blast wave and winds ⁱ strong enough to overturn an army M113 armored personnel carrier oriented sideways to blast
Fractionating towers in 15Q7 tetraethyl lead manufacturing and in crude refining and synthetic oil petroleum manufacturing (pp. 1-6, 1-10)		12.98	1.14	227.6	362.1	Overturning of towers	Blast winds heated ^g by about 100 deg F above ambient temperature due to sudden compression of air
Tanks, artillery, anti- aircraft artillery, anti- tank guns, and infantry weapons (p. 1-16)	13P0	12.00	1.19	208.2	340.3	Light damage	Blast wave winds strong ^f enough to loft boulders weighing 10 pounds
Nitrogen, synthetic ammonia and nitric acid storage tanks in chemical manufacturing plants, and surface storage tanks in crude refining and synthetic oil petroleum manufacturing (pp. 1-6, 1-10)	12P0-13P0	10-12	1.2-1.3	169-208	294-340	Rupture and distortion, and loss of contents of storage tanks.	
Multistorey steel framed or reinforced concrete administration buildings at Naval operating bases (p. 1-19)	12P0 12P2:	10.00 change psi	1.32	169.2	293.9 change wind speed	Severe damage to contents by blast and debris which precludes operations until major repair or replacement is effected	
Rail mobile missile car, carrying empty, horizontal missile (ICBM type) (p. 1-18)	14Q8	9.81	1.33	165.6	289.4	Car overturned and missile crushed	

**Table of Nuclear Effects for 300kt Nuclear Weapon:
A Comparison of Damage Predicted by the *Physical
Vulnerability Handbook*^a and Damage and Effects Not
Predicted by the *Handbook*^a**

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PVH ^a Descriptions of Targets	VNTK ^b	Peak Over- pressure (psi)	Range (miles) ^c	Thermal Fluence ^d (cal/cm ²)	Wind Speed ^e (mph)	PVH ^a Damage Assessments	Notes on Damage & Effects Not Considered in PVH ^a
Blast furnace and integrated works plant in manufacture of steel (p. I-11)	13Q6	9.49	1.35	159.4	281.6	Overturning of blast furnace superstructure; collapse and rupture of coke- chemical gas mains resulting in destruction of exhausters; collapse of coke- chemical overhead piping; overturning of blast furnace superstructure; severe damage to control houses and controls of blooming and rolling mills; collapse of gas and air system mains (minimum repair time at least 6 months)	Fireball momentarily ^h delivers light and heat at about 5000 times that of a desert sun at noon
Rail mobile missile liquid fuel tank cars (ICBM type) (p. I-18)	13Q6	9.49	1.35	159.4	281.6	Car overturned and contents lost	
		8.7	1.4	143	260		Wind speeds from ^j nuclear blast as high as those in the .1% most intense tornados
Chemical manufacturing: cobalt refining process buildings; nitrogen, synthetic ammonia and nitric acid synthesis buildings and converter and concentration buildings; sulfuric acid contact process converter building Chemical manufacturing: tetraethyl lead principal processing area (p. I-6)	13Q7	8.85	1.41	147.1	265.8	Severe structural damage to buildings General blast and debris damage to buildings control equipment, overhead piping, process tanks, etc.	

**Table of Nuclear Effects for 300kt Nuclear Weapon:
A Comparison of Damage Predicted by the *Physical
Vulnerability Handbook*^a and Damage and Effects Not
Predicted by the *Handbook*^a**

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PVH ^a Descriptions of Targets	VNTK ^b	Peak Over- pressure (psi)	Range (miles) ^c	Thermal Fluence ^d (cal/cm ²)	Wind Speed ^e (mph)	PVH ^a Damage Assessments	Notes on Damage & Effects Not Considered in PVH ^a
Aircraft: engine machine shops and airframe assembly buildings (p. I-5)	13Q7	8.85	1.41	147.1	265.8	Severe structural damage to buildings	
BEER CAN, DOG HOUSE, and HEN HOUSE guidance radars (p. I-19)	13Q7	8.85	1.41	147.1	265.8	Severe damage to radar structure	
Electric power: thermal electric power plants, steam generation (p. I-7)	12P2	8.76	1.42	145.3	263.5	Crushing of boiler walls, stack breachings and fan housings; overturning of stacks; some rupturing of piping (minimum repair time approx. 6 months)	
Missiles (SAM): missile horizontal - in the open (p. I-18)	12Q6	7.85	1.50	128.2	240.4	Missile and launcher overturned and missile destroyed	
Light bombers and fighters, swept wing, subsonic, oriented nose-on (Fagot, Fresco, Flashlight) (p. I-17)	10P0	6.94	1.60	111.2	216.6	Light damage to aircraft consisting of structural failure of small control surfaces, bomb bay doors, wheel doors, fuselage skin damage, and damage due to flying debris. Requires 1-4 hours to repair but may permit limited flight	Wind speeds from nuclear ^k blast higher than those in the most intense and violent of hurricanes Ignition and fire effects due to heating by the fireball of surfaces on the target similar to those described for randomly oriented medium bombers at range of 2.25 miles (see below), but considerably more intense at this range flight
3-8 story commerical and residential buildings with masonry load-bearing walls (p. I-4)	10P0	6.94	1.60	111.2	216.6	Severe structural damage to buildings	
Rail mobile missile liquid oxygen tank cars (ICBM type) (p. I-18)	12Q8	6.72	1.63	107.0	210.6	Cars overturned and contents lost	

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PVH ^a Descriptions of Targets	VNTK ^b	Peak Over- pressure (psi)	Range (miles) ^c	Thermal Fluence ^d (cal/cm ²)	Wind Speed ^e (mph)	PVH ^a Damage Assessments	Notes on Damage & Effects Not Considered in PVH ^a
Chemical manufacturing: electrolytic cell buildings, sulfuric acid chamber process building, chemical warfare agent process building (p. I-6)	11Q7	6.07	1.73	95.1	192.8	Moderate structural damage to building	Fireball momentarily ^h delivers light and heat at about 3000 times that of a desert sun at noon
Shipbuilding, small vessels and submarines: cranes in shipways and fitting- out areas (p. I-11)	11Q7	6.07	1.73	95.1	192.8	Overturning light portal and tower cranes	
Medium and heavy bombers, subsonic, oriented nose-on (Badger, Bear, Bison) (p. I-17)	9P0	5.79	1.77	90.0	185.0	Light damage to aircraft (see above)	Thermal effects similar to those described for randomly oriented medium bombers at range of 2.25 miles (see below), but considerably more intense at this range
Missiles (SAM): missile vertical - revetted (p. I-18)	10Q5	5.71	1.78	88.6	182.9	Missile and launcher overturned and missile destroyed	
Railroad yards and equipment: control and switch towers (p. I-13)	9Q3	5.20	1.88	79.4	168.4	Overturning	Cars, buses and trucks ^l overturned by winds accompanying blast wave
Ballistic liquid fueled missile erect and empty, soft sites; IRBM or ICBM types (p. I-18)	11Q9-12Q9	5-6	1.7-1.9	75-94	162-191	Missile overtured and destroyed; some components salvageable	
Road mobile missiles, IRBM types: missile transporter, carrying empty, horizontal missile; launch control, checkout, power and air conditioning van trucks or trailers (p. I-18)	11Q9	4.97	1.92	75.3	161.9	Transporter overturned and missile crushed; vehicles overturned and contents severely damaged	

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Light bombers and fighters, swept wing, subsonic, randomly oriented (Fagot, Fresco, Flashlight) (p. I-17)	9Q6	4.47	2.04	66.4	147.3	Light damage to aircraft (see above) .	Fireball momentarily ^h dellivers light and heat at about 2000 times that of a desert sun at noon. Thermal effects similar to those described for randomly oriented medium bombers at range of 2.25 miles (see below), but considerably more intense at this range
Aircraft Carriers (p. I-20)	7P0	4.02	2.16	58.5	133.7	Slight reduction in weapon- delivery efficiency due to equipment or topside structural damage, or to personnel casualties	
Field fortifications: foxholes and trenches, unvetted, at Nevada Test Site (p. I-16)	7P0	4.02	2.16	58.5	133.7	Less than 10 percent filled with earth	
		3.8	2.2	55	127		Blast wave and ⁱ winds strong enough to overturn a 1/4 ton M38A1 army truck oriented sideways to blast
Medium and heavy bombers, subsonic, randomly oriented (Badger, Bear, Bison) (p. I-17)	7Q2	3.72	2.25	53.4	124.8	Light damage to aircraft (see above)	Bare aluminum surfaces warp and melt from heating by fireball. Aircraft tires and interiors exposed to direct light of the fireball are ignited and burn. Interiors of aircraft support trucks set on fire. Exposed fueling hoses set on fire. Metal artillery ^j components warp or fuse
		3.5-6.4	1.7-2.3	50-100	118-202		

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PVH ^a Descriptions of Targets	VNTK ^b	Peak Over- pressure (psi)	Range (miles) ^c	Thermal Fluence ^d (cal/cm ²)	Wind Speed ^e (mph)	PVH ^a Damage Assessments	Notes on Damage & Effects Not Considered in PVH ^a
Tree blowdown areas: unimproved natural conifer forests in Western Europe and Southeast Asia that have developed under favorable growing conditions, light and heavy underbrush (p. I-16)	8Q6-9Q4	3.7-5	1.9-2.3	53-75	125-162	90,000 feet of down tree stem per acre - 90% of trees blown down	
Communications: 150 feet high microwave tower (p. I-16)	7Q4	3.43	2.35	48.4	115.8	Collapse of tower	
Single and multistory commercial wood framed buildings (p. I-4)	6P0	3.35	2.38	47.0	113.3	Moderate structural damage to buildings	Wind speeds from nuclear ^j blast higher than that of most tornadoes
END TRAY and FAN SONG mobile guidance radars [SA-2 Air-defense Engagement radars] (p. I-19)	6Q7	2.40	2.86	31.2	83.0	Van overturned (van not revetted)	
Corrugated asbestos siding; corrugated steel or aluminum paneling; wood siding panels, standard house construction (p. I-4)	4P0	2.33	2.90	30.1	80.7	Shattered and blown away, occasional frame failure; connection failure followed by buckling; failure at main connections allowing a whole panel to be blown in	Fireball momentarily ^h delivers light and heat at about 1000 times that of a desert sun at noon
		2.2	3	27	75		Winds associated with ^j nuclear blast wave achieve hurricane force
		1.7-4.7	2-3.5	20-70	59-152		Metal components ⁱ in machine guns and rifles warp or fuse
		1.7-3.5	2.3-3.5	20-50	59-118		Heavy damp clothing and ⁱ damp rubber tires ignite

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PVH ^a Descriptions of Targets	VNTK ^b	Peak Over- pressure (psi)	Range (miles) ^c	Thermal Fluence ^d (cal/cm ²)	Wind Speed ^e (mph)	PVH ^a Damage Assessments	Notes on Damage & Effects Not Considered in PVH ^a
		1.7-2.2	3-3.5	20	76-60		Thermal fluence ^l (20 cal/cm ²) at which ignitions ^m from heating of surfaces by the fireball make mass fire almost certain (visibility from 5 to 10 miles)
		1.4-2.3	2.9-3.9	15-30	48-80		Many ignitions of damp ⁱ vegetation
Glass windows, large and small (p. I-4)	1P0	1.35	3.91	15.0	47.9	Windows shattered, occasional frame failure	Sand illuminated by ^l fireball explodes from differential heating of particle surfaces
HEN HOUSE fixed guidance radar (p. I-19)	OP0	1.12	4.31	11.7	40.2	Severe damage to antenna	
		1-1.5	3.7-4.6	10	36-53		Thermal fluence ^l (10 cal/cm ²) equal to that at the outer limit of the mass fire zone at Hiroshima (visibility from 5 to 10 miles)
		.9-1.2	4.1-5	8	44-31		Coarse grass ignites ^l (visibility from 5 to 10 miles)
		.9-1	4.6-5	8-10	31-36		Third degree skin ^l burns
		.8-1	4.5-5.1	4-6	30-37		Many ignitions of dry grass and leaves (5 mile visibility)
		.8-1.4	3.8-5.3	7-16	28-50		Rubber and plastics ⁱ melt
		.6-1	4.7-6	5	22-34		Deciduous leaves ignited ^l (visibility from 5 to 10 miles)
		.5-.9	5-6.5	4-8	19-31		Second degree skin burns ^l
		.5-.7	5.6-6.5	4-6	19-25		Many ignitions of dry grass and leaves ^l (10 miles visibility)

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Footnotes:

- (a) Defense Intelligence Agency, *Physical Vulnerability Handbook--Nuclear Weapons* AP-550-1-2-69-INT (Washington, D.C.: Defense Intelligence Agency, 1 June 1969, with change 1 [1 September 1972] and change 2 [28 January 1974]).
- (b) Explain codes of VNTK briefly
- (c) Ranges are those at which a 300 kt near-surface burst results in the indicated peak overpressure.
- (d) Thermal fluences calculated assuming scattering and absorption coefficients recommended by Harold L. Brode. "Review of Nuclear Weapons Effects", *Ann. Rev. Nuc. Sci.*, Vol. 18, March 1968, pp. 153-202. Visibility is assumed to be blah blah.
- (e) Wind speeds and wind forces calculated from the Rankine-Hugoniot equations
- (f) Author's estimates, using Rankine-Hugoniot equations to estimate the velocity and density of air in a shock wave. The drag coefficient for lofted objects is assumed to be about .2 for all wind velocities.
- (g) Author's estimates, using Rankine-Hugoniot equations to estimate the temperature of air in a shock wave.
- (h) The amount of radiation delivered at the earth's surface by a desert sun at noon is about 1000 watts/m². The fireball generated by a 300 kt detonation achieves its maximum brightness about one half second after the detonation begins. Hence, 1000 times brighter than a desert sun at noon means that the fireball delivers about 1,000,000 watts/m² at that time.
- (i) Data from Lloyd E. Johnson, Harold L. Brode, and Richard D. Small, "Analytical Models of Weapons Effects for Nuclear Warfare Simulation", Pacific-Sierra Research Corporation Research Note 5996, July 1984.
- (j) T. T. Fujita, "Tornadoes Around the World", *Weatherwise*, 26, pp. 56-62, 78-83, 1973
- (k) E. Palmen and C. W. Newton, *Atmospheric Circulation Systems*, Chapter 15, 1969.
- (l) Data adjusted from table 7.40 in Samuel Glasstone and Phillip J. Dolan, "The Effects of Nuclear Weapons", 1977, U.S. Department of Defense and U.S. Department of Energy. Thermal fluences for a 300kt yield derived by fitting a logarithmic spline to values given for different yields.
- (m) Note that a 100% change in visibility, from 5 to 10 miles, results in a change in the range at which 20 cal/cm² is deposited of about 17%. A review of weapons tests measurements indicates that there is an uncertainty in the range at which a given peak overpressure occurs of about plus or minus 15%. The uncertainty in range associated with wind effects is even larger. The commonly stated claim that fire ignition ranges are more unpredictable than blast effects is therefore not supported by a review of weapons effects uncertainties. See Harold L. Brode, "Review of Nuclear Test Peak-Overpressure Height-of-Burst Data", Pacific-Sierra Research Corporation Research Note 353, November 1981.

7/7/95 and 10/25/95

Chapter 2

FRAMING THE PROBLEM

From the early 1950s to the present, why have the calculations of damage caused by nuclear weapons developed by the U.S. government considered only blast effects? Why have thermal effects (and the interaction of thermal effects and blast effects in causing fires) not been calculated as a cause of damage? What accounts for this astonishing omission in damage prediction?

In this chapter I first present six explanations I have encountered and explain why I have chosen not to use them. I then explain my own approach and argument. The argument I develop explains why and how, historically, an organizational understanding developed in which damage caused by blast effects seemed to be more predictable than damage caused by thermal effects. My basic strategy will be to show how organizational pre-understandings shaped later inquiry, resulting in much greater knowledge regarding blast effects than thermal effects. I claim that this resulted from the choices of actors, not from "nature" itself. In other words, pre-existing organizational ways of knowing and doing -- or "frames" (a concept I will elaborate below) -- incorporated assumptions and knowledge about the world, articulated or assumed purpose, defined problems, and, in focusing organizational attention and resources, shaped the search for solutions.

Clearly, there are other ways one could explain how the routinized predictions by the U.S. government of the effects of nuclear weapons came to be based solely on blast effects, and thermal effects were not taken into account. In a sense, there are few explanations and many. There are few in

that this question simply has not been addressed in the historical or social science literature, and there is only a small literature on closely related problems of other nuclear weapons effects, such as how radiation effects were understood.¹ There are many in the sense that there are a number of apparently plausible explanations grounded in science, morality, psychology, and social science.

POSSIBLE EXPLANATIONS²

Those in the nuclear targeting and weapons effects communities provide three explanations for why blast effects, but not thermal effects, have been incorporated into nuclear targeting routines. All three seem to be grounded in the physical world, that is, in the nature of “nature” itself.

Blast effects are more predictable than mass fire. In the most widely held view by those in the nuclear weapons effects and nuclear targeting communities, the thermal effects of nuclear weapons are too unpredictable to be calculated as a cause of damage. These analysts do not disagree that under certain conditions, a nuclear weapon detonation would cause a mass fire. Given hypothesized initial conditions, the calculations regarding blast pressure and thermal fluence presented in chapter 1 are not controversial and are based on widely accepted understandings, codified in standard treatments of the effects of nuclear weapons.³ There is no controversy that a mass fire occurred at Hiroshima and that it burned out an area of approximately 4.4

¹fn Hacker, a couple of other things.

²Think about for later draft: Dessler suggests changing order of arguments: human reactions (args 4 and 5 below that incendiary warfare is immoral and incendiary warfare is psychologically repellent), then easily rejected physical arguments (args 2 and 3 below that blast is more important and that evidence of fire damage was weaker), then the physical hypothesis that needs to be taken seriously (arg. 1 just below that blast effects are more predictable than mass fire), and finally another completely different approach (arg. 6 below re org. interest), one that in fact leads one to pursue Eden’s historical analysis.

³Glasstone; Eden, nfa interview Pentagon, October 3, 1991.

square miles. Finally, the mechanisms by which a nuclear detonation could ignite fires is not disputed: the deposition of thermal energy on combustible materials, structures and containers breaking apart from blast, and the spread of fire from radiant heat, sparks, and firebrands.

But here agreement ends. In the dominant view, neither the probability of a mass fire nor the magnitude of such a fire following a nuclear detonation can be reliably modeled and predicted. This is because the conditions under which mass fire would occur are so complex, variable, and uncertain as to defy reliable prediction as to when such fires would occur and at what range such fires would burn. In other words, the physical processes are too complex and too variable to be predictable. Most important, numerous environmental variables strongly affect whether a mass fire will occur: terrain, humidity, rainfall, temperature, time of year, and prevailing wind conditions. In addition, these interact with variables associated with targeted structures, particularly the amount of combustible material comprising structures and the amount of combustible material comprising building contents. Finally, the physical processes involved in igniting a mass fire are highly complex and little understood. Because of the complexity of the interactions among environmental variables, structures, and the processes of ignition, damage caused by fire is inherently less predictable than damage caused by blast effects. These uncertainties make the development of a system for predicting damage from thermal effects an exceedingly difficult -- indeed, a too difficult -- undertaking. Thus, although a system for predicting damage caused by blast effects may, in some cases, understate damage, because blast effects are inherently far more predictable than thermal effects, it makes sense to base predictions of damage caused by a nuclear detonation on blast effects alone.

This view is very widely held by serving and retired military officers -- from Air Force colonels to high-ranking generals and admirals; by civilians inside the government, including intelligence officials and civilian defense officials; by consultants outside the government; and within that part of the academic community concerned with nuclear weapons policy.⁴

This view is well captured in the words of a thoughtful Air Force officer:

There's great variation in trying to calculate [thermal effects], variation in whether the windows are open or shut, whether the curtains are drawn or not, whether there's rain or snow, the time of year, the rainfall, humidity. Hiroshima and Nagasaki were largely paper cities. The fire effects were tremendous. But there's great difficulty in calculating fire effects....For large structures -- large buildings like those on Penn Ave. or Constitution Ave., government buildings, like the Treasury Building -- if the windows are closed and the curtains down, thermal may not do it.⁵

Similarly, according to a recently retired high-ranking Naval officer:

In Russia, or in other countries in that region, the time of year, the vegetation, the petroleum distribution system, the natural gas distribution system, all of those things have to be in a fire algorithm

⁴The infeasibility of predicting damage from fire was a dominant theme in many conversations and interviews I held in the early 1990s with numerous people [among them, RC, July 3, 1990; DIA, BK, GX, BP...] This is not to say that the view is unanimous. It is not, quite. In addition to the physicists mentioned above, Postol, Brode, and Brode's associates, a very small number of weapons effects analysts inside and outside the government do not accept the standard answer, either because they have been impressed by the magnitude of thermal effects and thus wonder why they have not been taken into account in the government's methodology [GB, EO] -- in the words of one of them, GB. on damn good question -- or because they have been convinced by the work of Brode and his associates that thermal effects can indeed be predicted [RR, BH].

⁵Eden, Interview, Washington, D.C., July 19, 1989. [maybe add that his nuclear effects friends tell him....]

somehow, and there's no way to do it, in all honesty....Time of year, day of the week, whether it rained yesterday or not, I mean it just [is] too cumbersome....There are too many variables.⁶

In sum, in the dominant view, the unpredictability of the thermal effects of nuclear weapons fully explains the omission of such effects in damage prediction. A large number of independently varying environmental conditions determine whether or not a mass fire will occur and the range of fire should it occur. This environmental variation cannot be reliably predicted and, therefore, the occurrence of mass fire, a highly complex phenomenon, and the damage resulting from it, cannot be predicted. In this view, it is not at all surprising that the U.S. government has long calculated damage on the basis of blast effects alone and has not incorporated the potentially damaging effects of thermal radiation and other phenomena that could lead to mass fire. There is no puzzle about the development of organizational knowledge. Indeed, the only puzzle is why, in recent years, a few scientists persisted in trying to develop a method to predict thermal effects, and why anyone would want to write a book about these issues.⁷

⁶(\nucs\interv\cxxxxx2.N93), side 1, ~321-331[check to make sure every word correct].

[do something with?] How do those who hold each view understand the views of the other? Those who are convinced that mass fire can be predicted believe, first, that their own analyses, which take both blast and thermal effects into account, subsume analyses focused only on blast effects, and second, that the more widespread understandings are simply uninformed about the physics of mass fires.

⁷material that followed in the text and probably should go somewhere [Dessler's comment: does this introduce new material? If not, omit. But he also has note: not summarized in chapter 1]:

The main point of difference in physical understanding between this widely held view and that of the physicists who claim that thermal effects can, and should, be incorporated into calculations of nuclear weapons damage effects is the role of environmental variables. In contrast to the dominant view just sketched, in the view of the physicists discussed in chapter 1, variations in environmental conditions produce generally minor effects. These variations are overwhelmed by the extraordinarily intense effects of the detonation itself, which inevitably would cause a very large number of ignitions, which would set in train a vast hydrodynamic pumping of air leading to mass fire.^{fn} [fn: Maybe use some of this material here or maybe use at end of chapter 1] However, as we saw in chapter one, physicists who have worked extensively on analyzing nuclear weapons effects have concluded that with modern strategic nuclear weapons

(having yields in the hundreds of kilotons), mass fire is overwhelmingly probable in the case of nuclear detonations near urban or suburban areas. This is because, first, in most circumstances, the probability of a very large number of fire ignitions is extremely high, and second, this large number of ignitions leads inevitably to physical processes – the bouyant rise of hot air and the resulting pumping of air in from the periphery -- that cause mass fire. Such fires would be of very great magnitude, extending far beyond the range of damage from blast effects alone. Further, the conditions under which mass fire would *not* occur, or would be severely attenuated, are limited and generally predictable. In other words, the importance of variation in the environment, for example, in weather conditions, is low because most conditions do not strongly affect the probability of mass fire occurring, and, in addition, those conditions that could affect the probability of mass fire can be modeled and controlled for in predicting damage. (Thus, if one were targeting a city like San Francisco in the summer, one would know that fog affecting the probability of mass fire would be likely.) Finally, because the physics of mass fires are well understood and can be modeled, the broad parameters of mass fire can be predicted. The uncertainties involved in predicting damage from mass fire are not greater than the uncertainties involved in predicting damage from blast effects.]

[Dessler says this paragraph should be put in the text.] The disagreement is not about whether only blast effects or only thermal effects can be predicted, nor is it about the relative merit of contending models for the prediction of thermal effects. Rather, it is about whether thermal effects can be predicted at all, specifically, whether a proposed physical model incorporating both thermal and blast effects is valid.

One aspect of this disagreement makes it extremely difficult to write about. I refer not to the substance of the disagreement but to the form of it. The disagreement is not one that has been resolved historically, that is, it is not a “closed” scientific controversy.^{fn} [fn: H. Tristram Engelhardt, Jr. and Arthur L. Caplan, eds., *Scientific controversies: Case studies in the resolution and closure of disputes in science and technology* (Cambridge: Cambridge University Press, 1987); also see Bruno Latour, *Science in Action: How to follow scientists and engineers through society* (Cambridge: Harvard University Press, 1987), pp. ---.] Disputes that have already been settled are far preferable for investigation by historians and sociologists of science because the scholar need not take a position on which understanding was correct. It is sufficient to explain how the actors themselves resolved the dispute. In this case, unresolved. work in: the analysis of those who claim that blah blah has not been directly rebutted. Despite the skepticism of most toward the idea that fire effects can be predicted, to my knowledge, there has been no scholarly rebuttal of the claim, either in the open or classified literature. In the policy realm, the claims have not been accepted. Those who hold the much more widespread understanding that mass fires cannot be predicted believe that the burden of proof lies with those who would claim to predict mass fire and that they simply have not proved their case. The rejection is not based on scientific papers but on a case not considered proven...

Given the lack of closure, I had two choices in shaping my argument. I could argue that the view of scientists that thermal effects can be predicted is, at the least, plausible, and therefore ask, given the plausibility of this position, why weren't thermal effects incorporated into predictions of damage? This position has the virtue of not taking a position in a debate that is not resolved, but the disadvantage of blunting the sharpness, and interest, of the question. Or, I could take the tack I have, which is to say that even though the controversy has not been resolved in policy terms, the claims that thermal effects can be predicted is far more powerful, convincing, and in all likelihood, correct than the competing argument, and to begin from that position. Just because an argument has not been resolved does not mean that one position is not correct.^{fn} [fn: Dessler made this point to me several times, until it sunk in.] Of course, this has the disadvantage that those who do not accept my position on this may not be interested in the argument that follows. It also puts me in a minority position among those who write about the sociology of science and technology. However, it has the advantage of

The argument that the focus on blast effects can be explained by the relative unpredictability of thermal effects includes both claims about the physical world and claims about the social processes by which scientific knowledge of nuclear weapons damage effects was discovered and applied. The implicit sociology is this: those who developed the organizational capability to predict damage from blast effects, the system for rating the vulnerability of structures to blast, correctly perceived physical reality and acted rationally in response to the physical environment. There was "good reason" for what they did, that is, they reasoned and acted correctly. In short, organizational knowledge was shaped by the physical world. Human perception and organizational choice followed unproblematically, and adaptively, as actors learned about, and responded to, the physical environment.⁸

Of all of the alternative explanations I present, this one poses the most important challenge to my argument. If this explanation is correct, then the very question I ask -- why thermal effects were not incorporated into organizational routines to predict damage from nuclear weapons -- is simply not interesting because the answer is completely obvious: the damaging effects of thermal radiation were not incorporated into routines to predict damage because such effects could not, and cannot, be predicted. That sounds

allowing me to pose the question far more strongly than I could otherwise, and also the virtue that it is what I think.

⁸Generalized, the underlying epistemology is one of rational action resulting from a correctly perceived environment. This is a "structural" explanation: to parsimoniously explain human action, we need only look to environmental determinants, including environmental constraints and incentives. (For an incisive discussion of classical theories of choice that assume "decisions will be uniquely determined by environmental constraints," see James G. March, "Decisions in Organizations and Theories of Choice," in *Perspectives on Organizational Design and Behavior*, ed. by Andrew H. Van de Ven and William F. Joyce. New York: John Wiley & Sons, 1981, pp. 205-244, at 207-210. An illuminating discussion on theories of adaptability in social science is Stephen D. Krasner, "Sovereignty: An Institutional Perspective," *Comparative Political Studies* Spring 1988.)

like a show stopper. In fact, it provides a very powerful alternative argument against which to test my claims that it was not the nature of "nature" that shaped knowledge, but rather that pre-existing organizational purpose, knowledge, and routines shaped scientific inquiry and subsequent knowledge of the physical world.

While it is not possible to test the validity of physical understandings in the social realm,⁹ it is feasible to test the possible histories implied by each argument.¹⁰ Indeed, the following historical chapters are, in large part, structured by these possibilities. What do those possible histories look like?

The argument that damage from thermal effects was not incorporated into damage-predicting organizational routines because these effects were far less predictable than blast effects -- in other words, that organizational knowledge was shaped by the physical world -- implies that the possibility of predicting damage from each effect was investigated and it was found that damage from thermal effects was less predictable than damage from blast

⁹Given a nuclear detonation, the determinants, probability, and effects of mass fire are completely independent of human understandings or investigations of it. At the same time, the issue of *predictability* of mass fire is a social one depending on: a) criteria regarding certainty of occurrence and measurement of the range of effects, and b) the state of scientific knowledge and computational capacity to predict.

~~[maybe use some of later? [Dessler says paragraph can be omitted]: It could be thermal effects are so highly variable as to not be predictable and that little effort was made to predict thermal effects. It could be so, but the historical process would not bolster the claim. It could also be that early efforts were made to predict thermal effects, it was found that thermal effects were not as predictable as blast effects, but that, in fact, thermal effects can be predicted. This would raise questions about why thermal was not considered predictable then and is considered so now. If answer resides in technology, physical understanding, etc., I would consider this to be a social explanation. add an important alternative: if effort made to predict thermal and found that it could not be done then, but now can be, why is this? a possibility i have kept strongly in mind during my investigation. it would change the weight of my argument from an emphasis on org. mission to one emphasizing the state of scientific knowledge. it would still be a social explanation]~~

[use? Of course it is not my purpose to write a scientific rebuttal to the dominant view. Indeed, I am persuaded that Brode and his colleagues and Postol have already done so.]

¹⁰use??? Such a test will be well worth doing because the alternatives provide a clear test of each argument. Also, the available historical material has not been explored empirically in regard to these questions.

effects. Such investigation could have occurred before the advent of nuclear weapons. Even if it were established with conventional incendiary weapons that the causes and consequences of mass fires were more difficult to predict than blast damage from high-explosive conventional bombs, we would still expect that in the post-war period considerable efforts would be made to understand the much more intense effects, both blast and thermal, from nuclear weapons.

By contrast, my argument that pre-existing organizational ways of knowing and doing shaped inquiry and resulting knowledge of the physical world implies a very different pattern of investigation. I would expect that greater resources and attention would be devoted to measuring and predicting damage from blast effects than from fire effects during World War II, and that a similar pattern would hold after the war with nuclear weapons.

What would argue *against* my claims that selective attention shaped the development of organizational knowledge? There are a number of possibilities. If, during the war, attention and resources regarding the prediction of damage from incendiary weapons became as great as the attention and resources devoted to prediction of blast damage from high-explosive weapons, this would challenge my claim that patterns of attention and knowledge gained during World War II shaped the development of organizational knowledge later. If, after the war, those experts who had been used to predict the effects of incendiary weapons during the war were consulted, or other potential experts -- for example, physicists at RAND -- were given contracts to develop their expertise in the prediction of thermal effects, this would argue against my claims of selective attention. If there were strong efforts made in the immediate post-war period to predict the

incendiary effects of atomic weapons, this would weaken my argument. Finally, if in post-war atmospheric nuclear weapons tests, equal resources and attention were put into predicting damage to targets from thermal effects as to predicting damage from blast effects, and especially if it were found that the variation and complexity of thermal effects precluded prediction of damage, this would argue strongly against my claim that organizational pre-understandings and routines shaped inquiry and knowledge. If such a process occurred, it would support the argument that the damaging effects of thermal radiation were not incorporated into organizational routines to predict damage because those effects are too variable, and their interactions too complex, to be predicted.

It is my contention that, although the history is quite complex, it bears out my claims. It will be the task of the following chapters to show *how* organizational pre-understandings shaped attention and capacity to predict damage from the blast effects of nuclear weapons and virtually precluded the ability to predict damage from thermal effects. I will show that actors' understandings of the requirements of prediction, that is, their understandings of what constituted adequate prediction, were strongly shaped by precision strategic bombing doctrine. I will also show how deep-seated actors' beliefs were in the greater predictability of blast effects than thermal effects and how those understandings both shaped, and were reinforced by, organizational capacities. Whether I can demonstrate this persuasively will, of course, be for the reader to decide.

Blast is a more important cause of damage. A widely-held view by those involved in nuclear targeting is that although nuclear weapons produce thermal effects, the damage caused by fire to targets of interest is, in

general, less than the damage caused by blast. The argument is commonly made that the United States historically has had a “counterforce” nuclear strategy and that the targets of greatest interest have been (and continue to be) relatively isolated or buried “hard” targets, especially missile silos and, somewhat more recently, deep underground government control bunkers. For these targets, fire would probably not occur, or, if it did, it would not be the primary cause of destruction. In the words of one Air Force officer, thermal effects “don’t matter for silos, deep underground structures. My nuclear weapons effects friends say if they try to do the same damage with thermal as with blast, you’ll be within the radius of the blast anyway -- against targets in which we’re most interested.”¹¹

In fact, there is no dispute that for important categories of counterforce targets, such as missile silos and other underground structures, thermal effects would not be the primary cause of damage. Were nuclear targeting historically confined to such structures, this would indeed seem to be an entirely satisfactory explanation.¹² However, not only has the United States historically targeted a much wider range of structures, many in or near urban areas, but *counterforce targeting of Soviet underground missile silos began over a decade after the U.S. methodology for predicting blast damage to structures was developed*. In other words, the targeting of hardened structures such as silos and underground bunkers cannot explain the emphasis on blast damage, which occurred well before such targeting began. Such retroactive explanation simply is not valid.

¹¹Eden, Interview, Washington, D.C. July 19, 1989. check quote to make sure no ellipsis before last sentence. fn Rathjens, though maybe not by name from 2nd MIT talk and other CISAC comments?

¹²It would not, however, invalidate a social constructivist approach. [The argument is simply that the organization’s goals, in this case, destruction of underground silos and structures, was understood to be best achieved in a certain way....]

A more important argument dates back to the early post-World War II period. Blast is a more important cause of damage than fire to targets of long-standing interest: industrial and other urban structures. The range of fire damage was understood to be less than the range of blast damage; in addition, it was argued that those structures at Hiroshima and Nagasaki damaged by fire had already been significantly damaged by blast by the time that fire occurred.

For example, statements in the U.S. Strategic Bombing Survey claimed that blast damage from the atomic bombs dropped on Hiroshima and Nagasaki extended beyond the range of damage caused by fire. Fire was not without effect, but where fire occurred, it “merely” intensified the damage caused by blast.

The structural damage to buildings in both cities was due to blast alone, blast and fire combined, and fire alone. Since *the limits of structural blast damage to buildings extended beyond the burned-over areas*, except for multistory, steel- and reinforced-concrete-frame buildings, it is believed that in most cases buildings which suffered mixed damage were structurally damaged by the initial blast, and *subsequent fires merely intensified the damage* [emphasis added].¹³

By 1950, the detailed descriptive statements -- and the caveats -- of the U.S. Strategic Bombing Survey became simplified and generalized in the forceful statement of the single most authoritative source in the open

¹³USSBS, *Report on Physical Damage in Japan*: 175. [More important: this statement first comes from USSBS, *Effects of Atomic Weapons on Hiroshima*, 2.] A similar assessment of damage in Hiroshima said, “*The primary cause of damage to buildings in Hiroshima was blast, similar to that caused by heavy charges of high explosive but on a much larger scale....In many cases, especially in steel-frame buildings, distortion was increased by the subsequent fires.* Structural blast damage to dwellings and other wood-frame buildings extended to 7,300 feet from ground zero, which was 1,050 feet beyond the fringe of fire damage” (emphasis added) (USSBS, *Effects of Atomic Weapons on Hiroshima*, Vol. 1, p. 16).

literature, *The Effects of Atomic Weapons*: "The shock wave produced by an air-burst atomic bomb is, from the point of view of...disruptive effect, the most important agent in producing destruction...."¹⁴

From my perspective, these early post-war understandings are important, but not as explanations. As with the argument that blast effects are more predictable than thermal effects, these are understandings of actors *to be explained*. We will see in some detail in chapter 4 that the contemporary evidence from the early post-war period on the relative importance of blast effects versus thermal effects was quite mixed, and open to different interpretations. (Even the brief quotation from the U.S. Strategic Bombing Survey, above, indicates the possibility of a different interpretation. Note the important exception regarding the greater range of blast damage compared to fire damage: "except for multistory, steel- and reinforced-concrete-frame buildings.") The task, then, will be to explain why the dominant understanding was that blast was a more important cause of damage than was fire.

Evidence of fire damage was weaker. Like explanations based on the predictability and importance of blast damage, a third explanation also appears to be based primarily on physical phenomena. This explanation, however, is more historical: blast effects, but not thermal effects, were taken into account in early targeting methodology because the remaining physical evidence, the evidentiary base from which to infer cause and predict effect on structures, was stronger for blast than for fire.¹⁵

¹⁴Los Alamos Scientific Laboratory, *Effects of Atomic Weapons* (1950), p. 45.

¹⁵For specific figures, see USSBS, *Effects of Atomic Weapons at Hiroshima*, 2: 5; and see especially the careful reanalysis of Hiroshima and Nagasaki data in H.L. Brode, et al, *Fire Damage to Urban/Industrial Targets*, PSR Report 1936, Contract DNA001-88-C-0055, Prepared for Headquarters Defense Nuclear Agency, Washington, D.C. (Los Angeles, California: Pacific-Sierra Research Corp., 25 July 1989), Vol. 2, *Technical Report*, Section 8, "Comparisons

According to a civilian scientist knowledgeable about the U.S. Strategic Bombing Survey's data on Hiroshima and Nagasaki:

They couldn't bridge the gap from successful fire raids [in Europe and Japan] to [analyzing] damage at Hiroshima and Nagasaki...because the evidence had disappeared. All they had was ashes. When they [the U.S. Strategic Bombing Survey] went in there a month later, all they had to look at was buildings destroyed by blast or that were noncombustible. What was destroyed by fire was gone. They were not able to provide any useful information about particular structures destroyed by fire because there was nothing left, just ashes and mortar. And it's very hard to look at a pile of ashes which have maybe already been cleaned up, or washed away, and decide you can learn much about what fire did and how it behaved in some structure. Whereas, if you find a building, masonry building or a steel frame building or even a wooden building that's been racked by the blast, you can at least determine at what range you got to the point where the damage was neither complete nor non-existent -- the incipient damage level.¹⁶

This expert drew out the ramifications for analysis. He explained that the scant remaining physical evidence regarding fire damage militated against developing a methodology to predict the physical vulnerability of structures to fire:

with Historical Urban Fires." In a goulish piece of bureaucratic understatement, the Strategic Bombing Survey offered a more social reason why the cause of atomic fire was so difficult to assess: for one-third of combustible buildings studied, "The probable cause of initial ignition...was not determined inasmuch as few people, present at the time of detonation of the atomic bomb, were available for interrogation" (USSBS, *Effects of Atomic Weapons on Hiroshima*, Vol. 2, p. 74).

¹⁶Eden, Interview, Los Angeles, Sept. 7, 1989; Eden, Phone conversation, April 13, 1990.

For the convenience of analysis of specific targets, in order to make a handbook of specific target response, they studied what they had. It defied much analysis. It was very difficult to take that kind of information and build a methodology of the vulnerability of structures to fires. It was easier with blast. The fire damage was by gee and by gosh, which was not satisfactory to engineers....Fire damage as specific damage mechanisms was considered quite unpredictable. Blast was considered easier to understand and predict....Nobody disputed that fire was a major damage mechanism but when it came to analyzing damage to specific targets, they felt more confident with blast damage.¹⁷

This is a fascinating account. Its importance lies not in the explanation regarding physical evidence, however, but in the insight it provides into how evidence, and lack of evidence, was construed, and in the questions it invites. We see the goals of the scientists and engineers involved in damage assessment at Hiroshima and Nagasaki: to analyze and predict the response of *specific targets* to blast and fire effects. Further, the engineers involved found fire damage and the specific "damage mechanisms" of fire *unpredictable*. Finally, analysts felt more *confident* predicting blast damage to specific targets. Why was such a high premium placed on predicting damage to specific targets? What kinds of engineers were involved in the analysis of damage? Were they civil, or what were then commonly called structural, engineers employed by the government in World War II to predict blast damage? Or were they "fire protection engineers," employed to predict fire damage? If they were predominantly civil engineers, would this explain why they felt more confident predicting blast damage? The requirements for specificity, in analyzing damage mechanisms in specific structures and in

¹⁷Eden, Phone conversation, April 13, 1990.

analyzing damage levels between no damage and complete damage, were demanding.¹⁸ However, as we shall see in chapter 3, this was not the only way that damage, and vulnerability to damage, could have been analyzed. For example, estimates of the range of complete destruction of virtually all structures could have provided the basis for an alternative method for predicting vulnerability. More than an explanation based on the availability of physical evidence, this account provides important insight and opens questions regarding collective understandings.

Two other explanations are grounded not in physical phenomena but in human reactions to incendiary warfare. One is based on morality; the other on psychology.

Incendiary warfare is immoral. One argument is that incendiary weapons have never been concertedly developed or widely used in the United States because such weapons, which can easily result in widespread and indiscriminate killing of civilians, have been morally repugnant. This argument has a more individual psychological casting, which I will discuss separately below. Here, I present the argument cast more socially. Based on two moral injunctions derived from St. Augustine -- not to kill noncombatants and not to use unnecessary force -- the injunction against the indiscriminate killing of civilians has long been incorporated into the international legal framework of war. This is not window-dressing but is taken very seriously by the U.S. military and has long been incorporated into the training of U.S. military officers.¹⁹

¹⁸use? As the account implies, this was done by analyzing the range at which structures of certain categories (for example, steel frame buildings of a particular size) would be damaged to specified levels, and then translating range to a standardized measure indicating the vulnerability of categories of structures.

¹⁹ This argument has been made to me forcefully and persuasively by George Bunn, former dean of the University of Wisconsin Law School and visiting whatever at the Naval War College.

I do not want to disregard this argument. Probably the most important effect of the moral injunction against indiscriminate killing has been as both a cause and a reinforcer of U.S. precision strategic bombing doctrine. Exactly how important moral considerations may have been in the shaping of early doctrine I do not know.²⁰ It is certainly clear that precision strategic bombing doctrine has been touted as being highly moral in its emphasis on discriminate targeting, and thus morality has served as an important justification for U.S. bombing doctrine, both before and after the advent of nuclear weapons. In addition, as we shall see in chapter x below, moral arguments were deployed during World War II (without great effect) by U.S. military officers opposed to the use of incendiary weapons. Finally, moral arguments have importantly shaped the presentation by the U.S. military of its bombing strategy, in part by causing it to redefine what is a military target and who (if anyone) is a civilian.

But the importance of moral considerations, whether as a shaper of doctrine, as part of internal policy debates, or as shaping public relations, should not be overstated. It did not stop the development and deployment of incendiary weapons during World War II. Although it is reasonable to think that moral views might have retarded the development of incendiaries in World War II, as we shall see in chapter 3, a more important cause of the lack of early development of incendiary weapons was that the agency responsible for them was far more focused on a no less discriminate weapon, gas. Further, as we shall see in chapters 4 and 5, there is no evidence that moral considerations played a role in the lack of development of a methodology for

Bunn is now consulting professor at the IIS, in residence at CISAC. [check text, including moral injunctions and St. Aug., with George.] add Jochnick and Normand cite.

²⁰after re-do next chapter say something like: It appears that rather than a direct cause of doctrine, it operated through public opinion.

predicting thermal nuclear effects after the war. Rather, issues of predictability and measurement were the focus on attention. (In any case, while moral revulsion could lead to a refusal to predict the incendiary effects of nuclear weapons, one might as easily predict that moral sensitivity would lead to an insistence on such development, so that weapons effects would not be underestimated.) Finally, without denying that U.S. military officers take seriously the injunction that unnecessary killing of civilians should be avoided, one simply must not overestimate the sensitivity of officers to enemy casualties in the face of the imperative to win the war being fought. In explaining the strategic bombing campaign against Japan in World War II, the officer who headed that campaign, General Curtis LeMay, wrote:

We were going after military targets. No point in slaughtering civilians for the mere sake of slaughter. Of course there is a pretty thin veneer in Japan, but the veneer was there. It was their system of dispersal of industry. All you had to do was visit one of those targets after we'd roasted it, and see the ruins of a multitude of tiny houses, with a drill press sticking up through the wreckage of every home. The entire population got into the act and worked to make those airplanes or munitions or war...[sic] men, women, children.²¹

²¹General Curtis E. LeMay with MacKinlay Kantor, *Mission with LeMay: My Story* (Garden City, NY: Doubleday & Co., 1965), p. 384. [check last sentence of this and fix it one way or another.] A more recent statement by a regular commentator on Air Force affairs has a similar tone: "The notion that vaporizing Japanese cities is unusually immoral is, rationally speaking, pretty silly....[W]hat is the moral difference between frying a jillion people serially with lots of everyday explosives and frying them in parallel with an atomic bomb?....The Allies liquidated cities all the time. How many kids do you think burned to death in cities like Dresden, Germany?....Mass killing of civilians was everyday stuff." (Fred Reed, "Hypocrisy and the Smithsonian," *Air Force Times*, November 7, 1994, p. 78.) A more recent statement by a regular commentator on Air Force affairs has a similar tone: "The notion that vaporizing Japanese cities is unusually immoral is, rationally speaking, pretty silly....[W]hat is the moral difference between frying a jillion people serially with lots of everyday explosives and frying them in parallel with an atomic bomb?....The Allies liquidated cities all the time. How many kids do you think burned to death in cities like Dresden, Germany?....Mass killing of civilians was everyday stuff." (Fred Reed, "Hypocrisy

Incendiary warfare is psychologically repellent. A closely related argument is that there is something psychologically repellent to the notion of dying, or inflicting death, by fire. Therefore, military officers and civilians shied away from using fire as an instrument of war. After the war, this repugnance accounts for a lack of interest in predicting the effects of mass fire as a cause of damage.

I would simply remind the reader that many aspects of military operations repellent to academics as they sit around conference tables, or to the larger public, are not beyond the ability of those responsible for carrying out war plans to consider and to implement. General LeMay's statement continued:

We knew we were going to kill a lot of women and kids when we burned that town. Had to be done.....The whole purpose of strategic warfare is to destroy the enemy's potential to wage war. And this was the enemy's potential. It had to be erased. If we didn't obliterate it, we would dwell subservient to it. Just as simple as that....There's nothing new about this massacre of civilian populations.²²

Further, I will argue below that neither moral considerations nor psychological sensitivity appear to have been at all relevant in the scientific exploration of nuclear weapons damage effects after the war. Prediction of damage was understood in terms of military operations and the application of scientific knowledge. If morality entered in, it was as an antecedent factor shaping understandings of military operations. But it was not so strong as to significantly constrain the limits of air operations in World War II. I simply

and the Smithsonian," *Air Force Times*, November 7, 1994, p. 78.) Add in cite and maybe quote from beginning of Rhodes, *Dark Sun*.

²²LeMay, *Mission with LeMay: My Story*, p. 384.

found no evidence of psychological factors influencing the focus on the blast effects rather than the thermal effects of nuclear weapons.

The above explanations for why thermal effects of nuclear weapons have not been taken into account in organizational routines to predict damage from nuclear weapons are all tailor-made in the sense that each has been offered to me by participants in the process or by those trying to explain the puzzle as I have presented it. The explanation below is a little different. I have derived it from an approach widely used in the social sciences. Like the argument that blast effects are more predictable than mass fire (albeit from an entirely different perspective), this explanation presents an important challenge to my claims.

The Air Force had an organizational interest in understating nuclear weapons effects. How can organizational interests explain how the Air Force generated knowledge about blast and thermal effects? Before addressing this directly, it will be necessary to say a few words about interest-based approaches to explanation. The basic way interest-based arguments work is by explaining the actions or preferences of actors (whether individuals or groups) on the basis of those actors' calculations of how to achieve or preserve an advantageous position in the future.²³ In other words, actions or preferences are shaped by actors' anticipations of broader future consequences.

When we explain the actions of organizations on the basis of organizational interests we generally mean that individuals or groups within an organization take certain actions with an eye toward gaining advantage for the organization in the future. Why would a cigarette company suppress certain kinds of scientific findings on the dangers of cigarette smoking? To

²³On interests, see Brian Barry(sp?), Pitkin, Geertz....

protect cigarette sales which strongly contribute to the future profitability and viability of the corporation. Why would a political party change a long-held position? To respond to public opinion polls indicating that by doing so the party would likely gain voters and win elections.

Interest-based arguments can take at least two forms. First, they can be deployed to explain specific historical events. X cigarette company did Y for the following reasons having to do with strengthening the corporation in the future. Second, interest-based arguments can be used more strongly to predict and explain proclivities of, or patterns of behavior by, actors. Corporations tend to suppress scientific evidence and to lie to the public in order to maintain and bolster market position. Military organizations tend to prefer offensive doctrines in order to reduce uncertainty, expand budget, and increase autonomy.²⁴ Politicians will kill their own grandmothers in order to gain or maintain political power. This second form of argument is more deductive, positing certain future advantageous states for categories of actors (for example, corporations, military services, politicians), requiring only minimal assumptions about human rationality (that actors seek to achieve advantage in the future), and holding over a large number of situations.

In security studies, interest-based arguments often take this second form. The organizational interests most commonly articulated in security studies are preserving organizational essence, expanding budgets and wealth, reducing uncertainty, and protecting autonomy and prerogative.²⁵ Morton

²⁴check list and exact wording.

²⁵Scholars have culled these ideas from the organizational literature and have used them deductively to explain procurement, military doctrine, and organizational bias. Barry R. Posen, *The Sources of Military Doctrine: France, Britain, and Germany Between the World Wars* (Ithaca, N.Y.: Cornell University Press, 1984); Jack Snyder, *The Ideology of the Offensive: Military Decision Making and the Disasters of 1914* (Ithaca, N.Y.: Cornell University Press, 1984); Stephen W. Van Evera, "Causes of War," Ph.D. dissertation

Halperin, who coined the term “organizational essence,” defines it as “the view held by the dominant group in the organization of what the [organization’s] missions and capabilities should be.” He articulates the essence of the U.S. Air Force as follows: “Since its inception as a separate service in the early postwar period, the dominant view within the Air Force has been that its essence is the flying of combat airplanes designed for the delivery of nuclear weapons against targets in the Soviet Union.”²⁶ The notion of “essence” adds a more ideational and idiosyncratic component to the concept of interest. However, Halperin and others deploy “essence” in a quite minimalist way, only slightly increasing the assumptions or information required to make broad deductions about expected behavior.

How might an interest-based argument explain how the Air Force generated knowledge about blast and thermal effects? One argument could be that given bureaucratic interests in preserving organizational essence, expanding budgets and wealth, reducing uncertainty regarding future planning, and protecting autonomy and prerogative, it was in the interest of the Air Force to claim that it needed more nuclear weapons and a larger

(University of California, Berkeley, 1984): 250-254, 295-298; add forthcoming Van Evera book. [check what Scott said re citations]

²⁶Morton H. Halperin, with the assistance of Priscilla Clapp and Arnold Kanter, *Bureaucratic Politics and Foreign Policy* (Washington, D.C.: Brookings Institution, 1974, p. 28. Halperin links missions to budgets by noting that in order to perform their missions effectively, some organizations, such as the military services, need to maintain expensive capabilities. Hence, such organizations will be particularly sensitive to budgetary issues (pp. 26-27). Far more than the relevant quotations convey, this is an important and deeply insightful work.

[work in? put in text? where?] With the partial exception of organizational essence, the power of such interest-based explanations is that with minimal assumptions about human rationality -- in particular, that actors seek to achieve advantage in the future -- they hold across a large number of situations. Mediating ideas and practices are deeply subordinated to the constraints and incentives derived from the environment. Variations in ideas and practices may explain odd outcomes, “outliers,” but are not essential in explaining most situations.

put somewhere? In other words, to provide powerful insight, statements of interest must adhere closely to the historical context, allowing us to understand in specific terms how members of organizations think they can achieve their ends, and more broadly, what ends they want to achieve. ~~transition: But to explain what actors in organizations want to do, and how, is to analyze organizational frames.~~

budget. One way to get more nuclear weapons would be to understate the effectiveness of those weapons, leading to a requirement for more weapons in order “to do the job.” Since thermal effects strongly contribute to the predicted damage resulting from nuclear weapons, the Air Force would tend toward more “conservative” measures that bolstered claims for more weapons. In this argument, an organizational interest in more nuclear weapons and budget deliberately skewed the pursuit of knowledge about those weapons and caused the Air Force to ignore or not pursue evidence that would not help it achieve its goals. This explanation of organizational action on the basis of incentives to preserve essence, increase size and wealth, reduce uncertainty, and protect autonomy is entirely plausible, and elegant in its parsimony.

Unfortunately, the identical conception of interests as easily leads to the opposite prediction: the Air Force would not have an interest in underestimating nuclear weapons effects but rather would *seek* evidence of damage from thermal effects in order to demonstrate the effectiveness of nuclear weapons. The greater the effectiveness of these weapons, the more impressed and likely those in the Executive Branch and Congress would be to fund more weapons and a larger Air Force budget.²⁷

The difference in these predictions is not in the understanding of organizational interests generally, or even of the organizational interests of the U.S. Air Force, but in the understanding of the meaning and political implications of weapons effectiveness in specific historical context. It appears that the general statements of interest dominant in security studies over the past decade do not serve as guides to understanding action, “in the absence of

²⁷Jack Snyder made this prediction to me in conversation (June or July, 199x. check date).

specific understandings as to how [interests or objectives] are to be achieved.”²⁸

Perhaps the fairest way to see these predictions is as hypotheses with which to examine historical evidence. Two kinds of evidence would be relevant. First, relevant would be evidence of internal Air Force calculations or discussions of the consequences to the organization in undertaking investigations that could lead to particular findings. Such evidence, whether in minutes or records of meetings or in other documents, would powerfully validate an argument about the role of organizational interests in shaping the acquisition of organizational knowledge.²⁹ This could include either positive decisions to undertake investigations because the results could be in the organization’s interest (as in Snyder’s guess that being able to predict thermal effects would provide grounds for further procurement) or decisions not to undertake investigations, or to undertake them in a certain way, so as to avoid findings that could be detrimental to the organization’s interests (as in the argument that thermal effects were not investigated because it was in the interests of the Air Force to underestimate weapons effects).³⁰

Second, also relevant, although less of a “smoking gun,” would be evidence regarding the context of decisions. If, for example, in the early Cold

²⁸Richard R. Nelson and Sidney G. Winter, *An Evolutionary Theory of Economic Change* (Cambridge: Belknap Press of Harvard University Press, 1982), p. 56. Also see the nice discussion by Lee Clarke....p. 164. For a vigorous challenge to the concept of interests held by Posen, Snyder, and Van Evera, see Elizabeth Kier, “ ”, Ph.D. diss., Cornell University, 1992.

Related, except for post hoc analysis, how does an analyst weigh the relative importance of each factor, especially given that there could be important tradeoffs among them? For example, it could be that in some situations protecting autonomy might have to be traded off against expanding budgets and missions. In other words, one cannot deduce from such broad statements of interest the particular preferences or choices of those in organizations. [use somewhere? But what desirable future states are, and what choices will lead to advantageous futures, is best understood when historically grounded.]

²⁹don’t look at x because of y consequences.

³⁰maybe add something about org. interests in legitimacy could lead to avoidance of investigation of thermal effects. not discussed above, but consistent.

War years, the Air Force had failed to gain congressional approval for requested numbers of weapons, had subsequently reduced estimates of weapons effectiveness, and, on the basis of those changed arguments, had gained approval of the original numbers sought, this would bolster the argument that it was in the interests of the Air Force to underestimate weapons effects and that such considerations were relevant in the case of investigating damage from thermal effects. Contrarily, if a careful examination of congressional debate showed that Congress was more likely to fund nuclear weapons when the Air Force claimed greater effectiveness, this would argue for an organizational interest in fully estimating, or even overestimating, weapons effects.³¹

In my research, I have not found evidence of deliberations within the Air Force regarding the organizational consequences of investigative findings of nuclear weapons effects. Nor have I found evidence that such findings would have been relevant in weapons procurement. On the one hand, the Air Force did not need to impress anyone regarding the effectiveness of nuclear weapons.³² On the other, I have found no evidence that greater nuclear weapons effectiveness would in any way have been detrimental. The specific understandings of weapons effects were secret, and it is not clear how such “technical” findings would have had organizational ramifications one way or another. This was one of the realms in which the military had great autonomy. Of course, the absence of a “smoking gun” does not mean such considerations could not have been present. But it does mean there is no

³¹something here about first always stronger, but one strength of interest-based arguments is that the evidence in the second can be powerful. weaker version: whole pattern based on imputed interests. (not unreasonable: pattern of congressional voting that is closely associated with campaign contributions is quite convincing even if no transcript of conversations.)

³²The U.S. Navy was not impressed with the effectiveness of nuclear weapons, but, although they could make trouble, they did not have a veto over Air Force budget proposals.

basis to claim it. (Let me add that, for the mid-1950s, I did find some reluctance on the part of the Strategic Air Command within the Air Force to incorporate into damage-predicting routines higher than originally expected estimates of damage from blast effects for high yield nuclear weapons. In other words, I did find an organizational proclivity to underestimate weapons effects in this instance. But this view served mainly as a note of caution and was not a major factor in the development of damage predicting routines.)

I am not claiming that interests do not exist or that they are not important. Particularly in an organizational or political context, I accept that many actions are undertaken with cold calculation of future consequences. However, such considerations do not explain the puzzle I am examining.

The kinds of general statements of interest that have been used deductively in security studies do not do the work that is required here, which is to explain how organizations come to want what they do, and how that shapes the knowledge they seek. For this, we need a much more historical approach. Halperin's notion of "organizational essence" is a step in the right direction, although the very term is ahistorical. We need to understand the genesis of organizational assumptions, purposes, understandings of problems and solutions in order to articulate context-specific understandings of interest. Once missions are articulated and commitments made -- in this case, to be able to inflict damage to specified targets from the blast effects of weapons -- actors will very likely try to perpetuate the organizational structures that allow them to carry out the actions to which they are committed. In other words, as organizational ways of knowing and doing are developed and maintained, interests emerge and coalesce around them. However, the key to explanation lies in

understanding the goals and conceptions of problems and solutions, not in efforts of actors to preserve and strengthen their organizational position in the future.³³ To argue otherwise is to put the cart before the horse.

In sum, I have argued against six possible explanations for why damage from thermal effects was not incorporated into damage-predicting routines developed by the U.S. government for use in nuclear war planning. I now present my own argument in detail, first describing the broad approach I adopt and then developing my argument regarding organizational frames in the U.S. Air Force. I then place my argument in the context of the broader literature. I explain how I have drawn from the sociology of technology and from organization theory. And I explain why I have devised an argument based on organizational frames and not used other interpretive notions, such as paradigms, discourse, culture, or epistemic communities. (Readers who are not particularly interested in the broader literature may wish to skip the last section, beginning on [~p. 44], and go directly to Chapter 3, where the historical account begins.)

SOCIOLOGY OF ORGANIZATIONAL KNOWLEDGE

The broad argument of the book is this: when actors found organizations and during periods of organizational redefinition or upheaval, actors create understandings, or knowledge, of the social and physical environment in which they must operate and of the goals of their organizational activities. These understandings of the environment and of

³³[dump probably: question is where the weight of explanation is to lie. if in understanding mission, then it is not really an interest-based argument. If in understanding calculations of consequence, then it is. In this case,....

problem with Halperin: his notion too schematic for our purposes and comes too late in the process. purpose matters as it shapes org. attention. args. about interest require more than showing that certain actions help an org. carry out a purpose or mission. they also include considerations of consequence.]

goals create for organizational actors frameworks for action: they generate problems to be solved and guide the search for possible solutions to those problems. The search for solutions is based on previous understandings, or knowledge, of the world, and leads to the creation of new knowledge and new actions. Once created, new understandings enable actors in organizations to carry out new actions and at the same time sharply constrain what those in organizations can do.

In this argument, organizational knowledge is not shaped directly by the physical world, but is socially constructed.³⁴ I certainly do not deny a reality outside the social, but our knowledge of that reality is always, and profoundly, mediated by the social: what actors already know, what they want to know, how they think they can go about learning more, and the criteria by which they judge and make new knowledge are not found in nature but are socially determined.³⁵ I accept the claim that “explanations for

³⁴By knowledge I mean actors’ representations of the world taken as reliable information. I refer to both explicit knowledge -- what actors think they know about the world -- and tacit knowledge -- what actors simply assume, or take-for-granted about the world., ~~or know how to do without necessarily knowing that they know how to do it.~~

By *organizational* knowledge, I mean representations of the world that are articulated or assumed at the organizational level, *between* actors within an organization. This is the knowledge that someone first coming into an organization must be cognizant of and appear to accept if he or she wants to be credible and effective. Many actors within an organization may personally accept organizational knowledge as true. But this is not necessarily the case. Individual actors need not accept, or fully accept, organizational knowledge for it to exert an overriding influence on organizational action.

³⁵On realism, see John Searle, *The Construction of Social Reality* (New York: Basic Books, 1995), pp. xx-xx. For a recent excellent discussion and response on the meanings of social construction, see Sergio Sismondo, “Some Social Constructions,” and Karin Knorr Cetina, “Strong Constructivism -- from a Sociologist’s Point of View: A Personal Addendum to Sismondo’s Paper,” in *Social Studies of Science*, Vol. 23 (1993), pp. 515-53, and 555-63. I thank Pascal Vennesson for bringing this to my attention. [alternative wording: The choice of problems to solve, the ability to solve problems, and the criteria that solutions must meet are not found in nature but are socially determined.] [keep? In other words, “physical reality” does not directly reveal itself but rather is apprehended in a social context on the basis of created analyses, methods, tools, and social expectations of what is “out there.”]

the genesis, acceptance, and rejection of knowledge claims...[must be] sought in the domain of the social world rather than in the natural world."³⁶

Thus, what has appeared self-evident to many actors, that blast effects are more predictable than thermal effects, is, for me, *the very thing to be explained*.³⁷ My starting point is to ask why, and how, this particular set of beliefs came to be organizational common sense. What was the origin of organizational understandings regarding the relative predictability of blast and fire? What level of precision in prediction was thought to be necessary and why? Why were these understandings dominant? And, what impact did such understandings have on how knowledge was developed regarding nuclear weapons effects? In sum, how did the organizational understanding develop in which damage caused by blast effects seemed, and, in terms of the organizational routines developed, *became*, more predictable than damage caused by thermal effects? (Similarly, one might choose to explain how dissenting views are constructed. I will pay attention to this, although the focus of my attention will be on much more widely-held understandings.)

Using a social construction perspective, I emphasize interpretation of the environment (or, more precisely, interpretations of the environment), choices made by actors, and contingent outcomes. But if contingent outcomes are uncertain, as by definition they must be, what can we say about how

³⁶Trevor J. Pinch and Wiebe E. Bijker, "The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other," in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, ed. by Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch (Cambridge: MIT Press, 1987), p. 18.

³⁷check to make sure I haven't lifted phrase from MacKenzie, Bijker, Pinch and Bijker, MacK and Spinard? If yes, then say something like: Thus, what may have appeared self-evident to actors at the time, that blast effects were more important than fire effects and that blast was inherently more predictable than fire, is precisely what must be explained on the basis of pre-existing understandings and social arrangements.

contingency is structured? Obviously our analysis should not be deterministic or teleological, but neither should it be infinitely plastic.

The basic strategy I employ in in this book is to understand past choices and actions as structuring future possibilities, both by shaping the pre-understandings that actors bring to new situations and by shaping the social environment in which decisions are made and carried out. Explanations that emphasize the process by which certain courses of action are eliminated or made less viable and others made the basis of future action are called "path-dependent" or "history-dependent" arguments. In John Ikenberry's words, "From this perspective, historical sequence and phasing become crucial to explanation....Choices made at one juncture limit choices made at subsequent junctures. A historical branching process takes shape with earlier political [or other] choices creating the circumstances and limiting the options in the intervening period."³⁸

Such explanations do not assume rational, efficient, or necessarily adaptive *outcomes*. Indeed, it is often the disjuncture between the analyst's

³⁸G. John Ikenberry, "Conclusion: an institutional approach to American foreign economic policy," in *The State and American Foreign Economic Policy*, ed. by G. John Ikenberry, David A. Lake, and Michael Mastanduno (Ithaca: Cornell University Press, 1988), p. 225. Discussion of history-dependence as a social process has been prominent in both sociology and political science. In sociology, see the classic article on the impact of founding processes (on organizational structure, not organizational knowledge) by Arthur L. Stinchcombe, "Social Structure and Organizations," in *Handbook of Organizations* ed. James G. March (Chicago: Rand McNally, 1965), pp. 142-193, esp. pp. 153-169; see also the recent excellent discussion of history-dependence by Walter W. Powell, "Expanding the Scope of Institutional Analysis," in *The New Institutionalism in Organizational Analysis*, ed. by Walter W. Powell and Paul J. DiMaggio (Chicago: University of Chicago Press, 1991), pp. 183-202. Two very good sophisticated introductions to institutional approaches in political science emphasizing history-dependence are: Stephen D. Krasner, "Sovereignty: An Institutional Perspective," *Comparative Political Studies* 21 (April 1988), pp. 66-94; and G. John Ikenberry, "Conclusion: an institutional approach to American foreign economic policy," in *The State and American Foreign Economic Policy*, ed. by G. John Ikenberry, David A. Lake, and Michael Mastanduno (Ithaca: Cornell University Press, 1988), pp. 219-243. And see James G. March and Johan P. Olsen, "The New Institutionalism: Organizational Factors in Political Life," *American Political Science Review* 78 (September 1984), pp. xxx-xxx.

understanding of the environment and the actors' understandings or actions that leads to a search for history-dependent processes.³⁹

Even more important is what path-dependent explanations tell us about historical *processes*. In contrast to explanations that understand changes in ideas and institutions as adaptive responses to changing environments, most path-dependent explanations emphasize continuities in ideas and "stickiness" in social processes, even when environments change.⁴⁰ Older ways of understanding and acting persist vestigially in time. In Ludwik Fleck's words, "[T]he past, complete with all its errors[,]....survives in accepted concepts, in the presentation of problems,...in everyday life, as well as in language and institutions. Concepts are not spontaneously created but are determined by their 'ancestors.'" ⁴¹

Given the emphasis on continuity and the weight of the past, how does a path-dependent argument explain change? I will discuss this in more detail below. For now, suffice it to say that path-dependent arguments do not claim that major change is brought about primarily by small, continuous (what used to be called evolutionary), adaptive increments. On the contrary, the

³⁹fn or quote Krasner.

⁴⁰fn Krasner.

⁴¹Ludwik Fleck, *Genesis and Development of a Scientific Fact* (Chicago: University of Chicago Press, 1979, originally published 1935), p. 20. Or maybe quote Schumpeter's coins that don't easily melt, in Skocpol article I think. Or maybe quote Marx: "Men make their own history, but they do not make it just as they please; they do not make it under circumstances chosen by themselves, but under circumstances directly encountered, given and transmitted from the past.") Karl Marx, *The Eighteenth Brumaire of Louis Bonaparte* (New York: International Publishers, 1963, based on 2nd ed. [Hamburg, 1869]), p. 15. [use? In this conception, organizational routines and the ideas embedded in them are "path-dependent," or "history-dependent," processes, in which early choices shape and constrain later possibilities. Routines and premises do not necessarily change immediately or rationally in response to the environment, but are often "sticky," that is, difficult to change and even self-reinforcing, thus strongly constraining what can and cannot be done by those in organizations.]

emphasis on “stickiness” implies disjunctive change.⁴² But I will come back to this.⁴³

Thus far, in trying to understand why in the early Cold War period the capability to predict damage from blast effects was developed and a parallel capability to predict damage from thermal effects was not, I have argued that the explanation does not lie in the physics of nuclear weapons detonations. Those who have examined the issue most closely have concluded that for higher yield nuclear weapons, thermal effects are significantly greater than blast effects and as predictable. Therefore, we should look historically at those factors that shaped the nature of the inquiry itself. I claim that organizational pre-understandings and existing social institutions shaped the acquisition of knowledge.

It is my task now to show how organizational ways of knowing and doing were deeply embedded in organizational routines and had an important effect in shaping knowledge regarding the effects of nuclear

⁴²Krasner....

⁴³what would an awareness of path-dependence processes alert us to look for when trying to explain social action?

re-do re choice points: First, disagreements among actors, whether muted or obvious, are good guides to understanding what was at stake, the points at which critical decisions might have been made, and how choices might have been different. [fn: thank Jackall] Such an approach does not assume process from outcome. If one cannot find significant disagreement, this does not necessarily mean that critical choices were not made and that outcomes were not contingent, but the argument becomes much harder to make (one may have to rely on counterfactuals), and such findings lend credibility to environmental or structural arguments.

[re-do re limiting options] Second, one can extend the second approach and go quite far back into the histories of organizations -- if not to origins, at least to early histories. By explicating early organizational ways of knowing and doing, by seeing early ideas and actions in context, one can identify foundational choices that may have had very long-lasting effects. Further, if in the early history one can find controversy, disagreement, or even uncertainty in the minds of actors as to their best courses of action, one can “denaturalize” historical processes and recover contingency. (In addition, earlier contexts may be surprisingly different from later ones; arguments and actions that may appear to be “common sense” in later periods can take on a very different cast in an earlier era. At the same time, in seeing a fuller historical context, one can better understand how the arguments made sense to participants. In other words, by exploring the earlier history of an organization, one gains both distance from current arguments and the empathy to understand their origins.)

weapons. How will I make such an argument? First, I will explain more formally what I mean when I say that actors in organizations create understandings that guide their actions. Then, it will be necessary to go back to the earlier history of the organization that became the U.S. Air Force to look for enduring understandings and to show how these understandings shaped later inquiry.

Organizational Frames. In the beginning of this section, I said that actors in organizations create understandings, or knowledge, of the social and physical environment in which they must operate and of the goals of their organizational activities. These understandings of the environment and of goals generate problems to be solved and guide the search for possible solutions to those problems. The search for solutions is based on previous understandings, or knowledge, of the world, and leads to the creation of new knowledge and new actions. Once created, new understandings enable actors in organizations to carry out new actions and at the same time sharply constrain what those in organizations can do.

In other words, actors in organizations shape their actions through frames. *Frames are ways of knowing and doing by those in an organization, coherent sets of organizing ideas and social practices, that structure how actors in organizations identify problems and find solutions. Frames incorporate assumptions and knowledge about the world, articulate or assume purpose, define problems, and shape the search for solutions.* Frames strongly shape organizational focus in problem solving and the means by which actors go about seeking solutions, and include how problems are represented, what counts as a problem, the strategies devised to solve problems, and the

constraints and requirements placed on possible solutions. More reflectively, frames provide accounts that explain organizational action to participants.⁴⁴

The broadest organizational frame discussed in this book is the precision strategic bombing doctrine of the U.S. Air Force. From the founding of a separate air service within the U.S. Army shortly after World War I, air force officers (then Army Air Service officers), defined the primary mission, or purpose, of their organization as the ability to destroy an enemy's crucial industrial and military assets through long-range strategic bombardment. By the 1930s, these officers refined U.S. strategic air doctrine to one of "precision bombing of the critical points of specified [enemy] target systems."⁴⁵ Precision strategic bombing doctrine was an organizational frame: it incorporated assumptions about the world (including understandings of the nature of warfare, the domestic political landscape, and future technological possibilities), understandings of purpose, and, as we shall see in more detail below, it shaped conceptions of problems to be solved and searches for solutions. It also explained to actors within the organization the importance of and reasons for their activities, and this in turn provided a basis for

⁴⁴My notion of frame is heavily indebted to Wiebe Bijker's definition of a (technological) frame. I have used a somewhat broader notion and explicitly placed it in organizational context. See Wiebe E. Bijker, "The Social Construction of Bakelite: Toward a Theory of Invention," in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, ed. by Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch (Cambridge: MIT Press, 1987), pp. 159-187, at p. 168. Bijker draws from Ludwik Fleck's classic *Genesis and Development of a Scientific Fact* (Chicago: University of Chicago Press, 1979, first pub. 1935). See also Wiebe E. Bijker, *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change* (Cambridge: MIT Press, 1995), check pp., cites, etc. [For my reference, here's the quote from Bijker (1987), p. 168: "A technological frame is composed of, to start with, the concepts and techniques employed by a community in its problem solving....Problem solving should be read as a broad concept, encompassing within it the recognition of what counts as a problem as well as the strategies available for solving the problems and the requirements a solution has to meet. This makes a technological frame into a combination of current theories, tacit knowledge, engineering practice (such as design methods and criteria), specialized testing procedures, goals, and handling and using practice."]

⁴⁵Thomas H. Greer, *The Development of Air Doctrine in the Army Air Arm, 1917-1941* (Washington, D.C.: Office of Air Force History, 1985, reprint of 1955 ed.): 57.

external legitimation. Precision strategic bombing doctrine was the dominant frame organizing air force activity. It has proved to be remarkably enduring.

I discuss two other organizational frames in this book. These frames were much narrower, more specialized, than bombing doctrine. One was a widely held “blast frame” centering on high explosive conventional bombs. Historically, it was contained within strategic bombing doctrine. The other was a less widely held “fire frame” emphasizing fire damage from incendiary bombs. Historically, it was less associated with strategic bombing doctrine. The blast frame and the fire frame were ways of understanding damage and predicting it in regard to conventional bombs. Both pre-dated World War II, and both became much more fully elaborated during that war.⁴⁶

Before I describe these frames, let me sketch out how frames are structured within organizations. To a great extent, frames are hierarchically organized, with lower-level frames nested within higher-level ones. To the degree that key organizational assumptions and organizational goals are not contested, there will be a dominant high-level frame shaping organizational activity. To the degree that key organizational assumptions and organizational goals are contested, there will be competing high-level frames and considerable organizational strife. Early in the history of the U.S. air

⁴⁶Let me anticipate the later history. I am not claiming that the blast frame and fire frame can be directly extrapolated to the present. The understanding of problems to be solved from the wartime blast frame carried over into the post-war realm of nuclear weapons and shaped the investigation of nuclear weapons effects. But nuclear weapons blast effects were of an entirely different magnitude from conventional blast effects and had a different phenomenology. To be able to predict damage from these effects required new knowledge. As new knowledge was gained regarding nuclear effects, the conventional blast frame became transmuted into a nuclear blast frame. The fire frame of World War II did not carry over into the analysis of problems or the understanding of nuclear weapons effects. The analysis of the scientists in chapter 1 is not properly understood as a fire frame or even as directly descended from that frame. It would most accurately be called a thermal-blast frame.

force, precision strategic bombing doctrine was established as the dominant high-level frame. There were no serious competitors.

Nested within higher-level frames are numerous lower-level frames. Such frames, linking problems and solutions, occur at every level of an organization -- from broad statements of organizational mission to many highly specialized problems and solutions.⁴⁷ Frames may be complementary (activities organized around specialized problems and solutions) or competitive (activities organized around conflicting diagnoses of situations or conflicting ideas about purpose that lead to conflicting formulations of problems and solutions).⁴⁸

Within the precision strategic bombing frame of the U.S. air force were many specialized (and sometimes competing) frames. These specialized frames included, among others, the problems and search for solutions related to designing, producing, and improving long-distance strategic bomber aircraft; the problems and search for solutions related to doctrine and operational art to guide the training of pilots in flying and bombing techniques; the problems and search for solutions related to understanding and choosing the structures to be targeted in strategic bombing operations -- including intelligence on, and mapping of, economic, political, and military structures, and developing analytical models linking expected physical damage to larger effects; and *the problems and search for solutions related to*

⁴⁷I draw on broadly similar arguments in the organizational literature. See Herbert A. Simon, *Administrative Behavior: A Study of Decision-Making Processes in Administrative Organization*, 3rd ed. (New York: The Free Press, 1976), pp xxxix, 5-11; Cyert and March, p. --; [Chandler?]; and esp. Neil Fligstein, *The Transformation of Corporate Control* (Cambridge: Harvard University Press, 1990). On org. cognition, see also Douglas.

⁴⁸[later? where? Lower-level frames may be complementary or competitive, more or less dominant, and more or less institutionalized in an organization. plus: fn to this: put around here??? Frames shape organizational routines and become institutionalized in them. Once routines are established, the routines and the conceptions embedded in them may persist long after the formative conditions have elapsed.]

both developing scientific understandings of the physical damage caused by bombs to targeted structures and applying those understandings to specific targeting problems and operations. It is the problems and solutions regarding the development and application of knowledge about physical damage from conventional bombs, and the processes by which understandings and organizational routines were carried over from conventional weapons to nuclear bombs, that I am concerned with in this book.

In the blast frame, high explosive conventional bombs produced damage to structures primarily by blowing them apart. There was a strong historical association between precision strategic bombing doctrine and understanding and optimizing blast damage. When U.S. bombing doctrine was first developed, the major weapons in the U.S. air arsenal were high explosive bombs. Those developing bombing doctrine assumed blast weapons; those developing blast weapons assumed precision strategic bombing doctrine. Each was predicated on the other. Further, because blast damage from bombs was discrete and spatially limited, it appeared to be highly consistent with U.S. bombing doctrine.

The problems and search for solutions related to blast weapons were tightly interconnected with other organizational activities, and, as I shall explain below, this is one reason why organizational change is difficult. The blast frame tied many people and organizational activities together. Aircraft design, aircraft crew training, and target selection were all predicated on the assumption that the salient damage to be produced would be blast damage from high explosive bombs. Aircraft were designed to carry high explosive bombs, not incendiaries; aircraft crews were trained only to handle high explosive bombs; and the targets selected often seemed more appropriate for

high explosive bombs than for incendiaries. Other activities were more directly connected to solving problems regarding blast damage, including research, development, and production of high explosive bombs, and prediction of damage to structures that would result from high explosive bombs.

In contrast, the fire frame emphasized fire damage from incendiary bombs. Because, under certain circumstances fire damage from incendiary weapons could spread far more widely than damage from conventional blast weapons, the fire frame rested less easily on the assumptions and aspirations of strategic precision bombing doctrine. Indeed, those professionals most closely involved in assessing and predicting damage from incendiary weapons tended to operate within a different doctrinal frame, in which “area” damage by fire, rather than “precision” damage by blast, was seen as more sensible and more effective. However, for U.S. political leaders and members of the U.S. military, area bombing was identified primarily with the British; American strategy was defined as different from this, and far more dedicated to “precision.” Both during the war and after, this was to limit the influence of those advocating research and development of incendiary weapons, including research to predict damage caused by fire.

How do we know a frame when we see one? This is an empirical question, and it can only be answered in the context of specific historical processes. What problems are actors trying to solve, and how do they conceive of solutions? What assumptions about the world and

organizational purpose do they bring to problem-solving? How do they explain the purpose of their actions?⁴⁹

Frames are located primarily in organizational routines. For example, in the 1950s, organizational procedures involved in nuclear weapons testing incorporated definitions of problems and were themselves searches for solutions. In addition, routines that are part of searches for solutions may result in routines that solve particular problems. For example, knowledge gained from nuclear weapons tests resulted in predictions about the damaging effects of blast from nuclear weapons; these predictions were then put in the form of an algorithm that could be routinely used by organizational actors to solve specific problems involved in targeting nuclear weapons. These actors who did not necessarily have a full understanding (or any understanding) of the physics involved (much like a sociologist might use statistical routines or “packages” on a computer without an in-depth understanding of the underlying mathematics). In other words, knowledge gained through organizational problem-solving may become incorporated into other organizational routines. Contained in such routines are frames: knowledge of the world, assumptions of purpose, definitions of problems, and conceptions of solutions. Knowledge-laden routines contain frames. They are organizational routines that embed knowledge for the purpose of solving certain kinds of problems.

But frames do more than shape organizational attention, knowledge, and action. *The process of identifying problems and finding solutions shapes organizations themselves.* As part of problem-solving activity, actors build

⁴⁹fn: use??? Competitive frames may be more or less dominant and (this is not the same thing) more or less institutionalized. add very lite illustration. Then say blast was dominant and blast more institutionalized.]

organizational capacity to solve problems, and this, in turn, affects relatively enduring features of organizations: the expertise brought into or developed by organizations, specialized activity to carry out large-scale research, and, as noted above, routines developed within organizations, including knowledge-laden routines that embody and apply knowledge gained in research activities. Thus, frames can be discerned not only in organizational routines, but in other enduring features of organizations: in organizational expertise and in specialized areas of activity.

This shaping of organizational capacity in the process of sustained problem-solving activities both enables and constrains. Available expertise, structured activities to carry out investigations, and knowledge-laden organizational routines all enable an organization to solve problems. At the same time, organizational capacity reinforces how actors in organizations define problems and search for solutions: certain expertise will not be brought to bear on problems, the organization will not be structured in certain ways to carry out investigations, and organizational routines will carry certain kinds of knowledge but not other kinds.

We have thus completed a circle: understandings of problems and of possible solutions shape organizational actions, including routines; sustained problem-solving activities shape organizational capacities; organizational capacities (in the form of available expertise, structures to carry out investigations, and knowledge-laden organizational routines) shape organizational understandings of problems and possible solutions. Frames shape actions (and are embedded in actions), which shape organizational capacities, which shape frames.

These self-reinforcing processes are sustained and deepened by three features of organizational activity. First, as organizations engage in problem-solving activities, they are likely to solve many problems! The competence and knowledge gained then contrasts all the more strongly with the lack of ability to solve other problems. Competence creates incompetence. The problem-solving path taken becomes far more attractive than other potential options.

Second, actors in organizations do more than engage in problem-solving activities. They also create accounts for themselves that explain why their course of action makes sense -- indeed, why the chosen course of action makes more sense than other possible courses of action. In creating such accounts, past organizational choice becomes reified. In the enduring insight of James March and Herbert Simon, "the particular categories and schemes of classification [an organization] employs are reified, and become, for members of the organization, attributes of the world rather than mere conventions."⁵⁰ In this process, a sense of contingency is lost, and frames become taken-for-granted.

Third, as people engage in problem-solving activities over a period of time, building competence and believing in the correctness and importance of what they are doing, they develop vested interests: they want to ensure a continued flow of resources into their area of activity to ensure that they can continue what they are doing and what they believe in.

⁵⁰James G. March and Herbert A. Simon, *Organizations*, xxx (1958), p. 165, quoted in Charles Perrow, *Complex Organizations*, 3rd ed. xxx (1986), p. 125. [check how much of this is directly from Perrow.]

How, then, do organizations change?⁵¹ The answer is: generally with great difficulty. The requirements for organizational change are daunting: conceptions of problems and solutions must be changed, as well as organizational routines, capacities, accounts, and vested interests. In other words, changing organizations means changing organizational frames, which are very deeply instantiated in organizational life.

If the impetus for far-reaching change comes from the top of an organization, changes in understandings of problems and solutions must penetrate throughout the organization. High-level directives will not be sufficient. If the impetus for far-reaching change comes from lower down in the organization, these changes must then be embraced by those at the top of the organization (whether by persuasion or by replacement of personnel) and must penetrate throughout. One persuasive account of change in organizations has it that powerful and well-connected actors within an organization redefine their external environment and the organization's goals, and then re-build career paths within the organization to empower those holding this new vision.⁵² In my terms, this is an argument that powerful actors reconceive organizational frames and then rebuild organizational capacity to implement new frames.

And what would cause actors to rethink the environment surrounding (and likely penetrating) organizations? The general mechanism posited is some sort of external change or shock.⁵³ But the key is not simply change in the environment itself, but how actors *interpret* the environment, including

⁵¹old passage on change: A tendency of routines and frames to persist, sometimes under radically changed circumstances, does not foreclose all possibility of change. It simply says that change, especially radical change, does not occur with great frequency, and when it does, it may occur relatively late and with some difficulty.

⁵²Rosen, IS and book.

⁵³Skowronek. Fligstein. Sewell? Nelson and Winter?

their understanding of the degree and significance of change. Probably the most likely impetus to reinterpretation of the environment, or organizational mission within it, is when key actors believe that organizational survival is at stake. Another likely impetus for change is when key actors believe that environmental change provides great opportunity. (Major change also occurs when one organization is taken over by another. In such a case, environmental change has swamped the targeted organization and other actors, who had been outside, come inside and impose their interpretations of purpose on the organization.)

The prerequisites for organizational survival vary by types of organizational environments, and this has strong implications for understanding change. For example, corporations in market economies are far more vulnerable to external challenges that may threaten their very survival than are military organizations in peacetime. Military organizations compete for budget, prerogative, and some missions, but, once established, military services generally do not threaten the very survival of other services by systematically competing to perform the *same* set of missions cheaper and better. Military services are buffered from external shock in other ways as well. There is, for example, no electoral accountability for military officers. And many crucial military matters are shrouded in secrecy. This means that military organizations in peacetime are relatively insulated from external shock and should be quite resistant to changes in frames.⁵⁴

⁵⁴[what about budget? changed political climate?][add: wartime: planning is hypothetically based. weight of mission is great. uncertainty great. org. is mission-driven and dependent on scenarios. failure]

THE BROADER LITERATURE

Sociology of Technology and Organization Theory. As the reader already familiar with the professional literature will have surmised, I have fashioned my argument out of two distinct literatures, the sociology of technology and organization theory.

There are some deep affinities between these literatures. Both are concerned with cognitive representations of the world. The sociology of technology is concerned with how communities of practitioners use representations of the physical and social world to produce technological artifacts. Organization theory is concerned with how actors in organizations use representations of the world as a basis for organizational action.⁵⁵ In addition, both are concerned with path-dependent processes.⁵⁶ Finally, both have developed or use explicit or implicit notions of frames.⁵⁷

⁵⁵Organizational theorists have long been concerned with how actors in organizations use representations of the world as a basis for organizational action. Almost fifty years ago, Herbert Simon alerted us to look for the premises regarding both fact and value which control organizational behavior and problem-solving. (Simon, *Administrative Behavior*, pp xxxvii, xxxix.) And in the late 1950s, James March and Herbert Simon argued that organizations devise schemes of classification that alter or filter out ambiguous, uncertain, inconsistent, and discordant information, in other words, that organizations "absorb" uncertainty and turn it into "fact." (James G. March and Herbert A. Simon, *Organizations*, xxx (1958), p. 165, quoted in Charles Perrow, *Complex Organizations*, 3rd ed. xxx (1986), p. 125. [check how much of this is directly from Perrow.] Also from the Carnegie School, see Richard Cyert and James March (cite.); and later work by James March and others working in the vein of organizational learning: (Barbara Levitt and James G. March, "Organizational Learning," *Annual Review of Sociology* 14 (1988): 319-40, and cite something in *Organizational Science*, Special Issue, *Organizational Learning: Papers in Honor of (and by) James G. March* 2 (February 1991).) Also see Simon's nice discussion of representation in *Org Science*.. [check by going back to text]

More recent work, particularly that of Neil Fligstein, has reformulated these insights to connote a fuller and more interconnected symbolic world than do the analytical images of "premises" and "filters." (Fligstein, *The Transformation of Corporate Control*. This is close to Mary Douglas's social cognition approach in *How Institutions Think*, which, like Bijker, draws on the work of Ludwick Fleck. [keep? The point is: recent analyses are more holistic, cultural, categorical (but not smarter)]

⁵⁶ Regarding organization theory, see Stinchcombe, "Social Structure and Organizations," and Powell, "Expanding the Scope of Institutional Analysis," cited in fn xx above and other essays in the collection of key articles and major new essays in *The New Institutionalism in Organizational Analysis*, ed. by Walter W. Powell and Paul J. DiMaggio (Chicago: University

Yet, despite these affinities, these literatures have been in very little dialogue. There is, for example, no discussion of the sociology of science or technology in a recent comprehensive volume on organization theory, and almost no reference to the literature in a recent organizational study of technology and organizations.⁵⁸

The lack of dialogue may be due, in part, to deep differences in intellectual style between the two literatures. On the one hand, the sociology of technology, and the closely related sociology of science and history of science and technology, tends toward a style of theorized case studies (much like anthropology), in which broad ideas are brought to investigations of

of Chicago Press, 1991). However, organization theory has generally talked about path-dependence more than demonstrating it. [is this too strong a statement?]

In an important recent book in the sociology of technology, MacKenzie argues that in competitive technological programs, the initial success of one program can lead to further funding and development and, at the same time, to the atrophy of funding and development for competitive programs. Thus, initial technical success can eliminate technical alternatives (MacKenzie, *Inventing Accuracy*, pp. 122-23, 212-213, 391.) MacKenzie does not use the term "path-dependent," but he is clearly referring to the same process as is Powell, who, writing from an institutional organizational perspective, defines a "path-dependent" or "history-dependent" process [chk] as one in which "initial choices preclude future options, including those that would have been more effective in the long run" (Powell, "Expanding the Scope of Institutional Analysis," p. 192).

⁵⁷In the sociology of technology, see the important work of Bijker, "The Social Construction of Bakelite: Toward a Theory of Invention," and *Of Bicycles, Bakelites, and Bulbs*: cited in fn xx above; [other Bijker cites on frames?] In organization theory the discussion has been more implicit. e.g., Simon. Fligstein does not use the term "frame" but the analysis is very similar. Barley? Orlikowski and Gash (pub. cite?), other Orlikowski? and Orlikowski (SCOR talk, winter 94/95 published?) do use a notion of frame broadly similar to mine. [check when have articles and say something nice.]

⁵⁸W. Richard Scott, *Organizations: Rational, Natural, and Open Systems* (Englewood Cliffs, NJ: Prentice-Hall, 2nd ed. 1987, 3rd ed. 1992); Paul S. Goodman, Lee S. Sproull, and Associates, eds., *Technology and Organizations* (San Francisco: Jossey-Bass Publishers, 1990); an exception is Karl E. Weick, "Technology as Equivoque: Sensemaking in New Technologies," in Goodman, et al, *Technology and Organizations*: 1-44. Important recent work that draws on both literatures: Orlikowski and Gash. get other Orlikowski cites. maybe add in Tushman? Thank Flank. [earlier? Important more recent literature uses the notion of paradigms (which for our purposes has the same meaning as frames), but takes them as givens. develop my point. say something about the mushiness of institutional args re cognition?] See discussion of Nelson and Winter in Dosi's article in *Social Construction of Technological Systems*, in which he says they take the DC-3 aircraft as a given paradigm [Lynn, look at Dosi and Nelson and Winter again]. Other treatments of cognition: Cyert and March, Douglas, Wilensky, that recent blah volume, *The Thinking Organization*.

specific cases and modified and elaborated in the course of inquiry. On the other hand, much organization theory, including some of the work I have found most valuable, tends toward the airy-fairy, striving to achieve broad theoretical statements about the nature of organizations and about the proper agenda for organizational research, and subordinating, or not engaging in, rich case studies. In practice, this has meant that relatively little attention has been paid to explaining the *processes* by which organizations develop knowledge. If organization theory has drawn our attention to the salience of categories in shaping organizational life, it generally has not shown in a detailed way *how* categorical choices are contested, made, and modified. This is, of course, the very thing at which studies in the history and sociology of science and technology excel.

In addition, the two literatures differ in the extent to which each employs a social constructivist approach. The sociology of science and technology generally employs a highly social constructivist approach, extending to the far reaches of relativism.⁵⁹ Institutional analyses within organization theory have tended toward a less thorough-going social constructivist approach. Some fairly recent institutional analyses have artificially separated “institutional” or symbolic environments from “technical” or market-driven ones. Other institutional analyses emphasize cultural aspects only in the diffusion of organizational forms and fall back on functional explanations for institutional origins.⁶⁰

⁵⁹cites

⁶⁰Dick Scott cite; Lynn Zucker cite; functional arg in Meyer? A good critique is Powell, “Expanding the Scope of Institutional Analysis,” p. xx. [here?] But see the excellent empirical works using social constructivist notions by Stephen Barley, -----, Neil J. Fligstein, ----, Orlikowski (SCOR talk?), other cites?

But if the sociology of technology has certain strengths -- richly theorized case studies and a deep and fascinating social constructivist approach -- this literature has not systematically studied organizations as the *locus* of the social shaping of technology and knowledge. In other words, the impact of organizations on the shaping of technology and the impact of technology on organizational life have been largely ignored.⁶¹ This may be because much work in the sociology of technology focuses on late 19th and early 20th century inventions ranging from artifacts, such as bicycles, Bakelite, and celluloid collars, to huge systems, such as the social and technological infrastructure involved in the generation, distribution, and consumption of electricity. Despite differences in scale, the locus of the social shaping and impact of technology is largely societal: the market, broadly conceived, where, on the one hand, networks of inventors, scientists, engineers, and entrepreneurs and, on the other, differentiated groups of potential consumers mutually shape artifacts and preferences. In this broad scheme, large-scale organizations are understood largely as producers of artifacts or as part of large-scale social and technological systems.⁶² The impact of internal

⁶¹Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge: MIT Press, 1990); Donald MacKenzie and Graham Spinardi, "The Shaping of Nuclear Weapon System Technology: US Fleet Ballistic Missile Guidance and Navigation," Parts 1 and 2, *Social Studies of Science* 18, nos. 3-4 (xxx - Nov. 1988): xxx-xxx, 581-624; and Graham Spinardi, *Polaris to Trident: The Development of U.S. Fleet Ballistic Missile Technology* (Cambridge: Cambridge University Press, 1994) are exceptions, although they do not explicitly draw on recent organization theory [check Spinardi]. In addition, the work of Thomas P. Hughes and his colleagues is deeply attuned to organizational issues. other exceptions in yellow, blue and red book....Check this fn with hist. or soc. of sci/tech.

⁶²citations from Bijker, Pinch, Hughes. In work on later inventions large-scale organizations are more prominent. For example, Edward W. Constant II, in *The Origins of the Turbojet Revolution* (Baltimore: Johns Hopkins University Press, 1980), uses as his main unit of analysis communities of technological practitioners, which may be in, or span, organizations. Yet Constant does not explore in any detail the impact of organizational assumptions or routines on invention, or the impact of invention on organizations routines. Rather, he focuses on technology in an open market ("people rarely buy either technological knowledge or technological systems in their entirety. In general, people buy artifacts (widgets) or the output of complex systems (electric light)...."), and portrays organizations as "technically required" in the "performance

organizational processes on the shaping of technology and knowledge regarding technology has not been the focus of attention.

Thus, the complementarity of these two literatures is clear. By expanding the concept of frames, which has been well-developed within the sociology of technology, to include important understandings about the embeddedness of cognition in organizational routines, we can arrive at a richer understanding of how knowledge is generated and sustained within organizations. In this conception, formative experiences in the histories of organizations (either at or near the time of founding or sometimes during turbulent periods of redefinition) shape organizational frames that are, as noted above, sets of organizing ideas and social practices that structure how actors in organizations identify problems and find solutions. Frames shape organizational routines and become institutionalized in them. Once routines are established, the routines and the conceptions embedded in them are likely to persist, even as the environment changes.

Other Interpretive Approaches. My argument, that organizational action can be explained by understanding the coherent sets of ideas and social practices -- the frames -- by which actors in organizations identify problems and solutions, is one of a number of contemporary social constructivist approaches that are deployed to explain social action. Social constructivist approaches are dominant in anthropology and prominent in "nouvelle" political science emphasizing interpretation of the environment.⁶³ These interpretive approaches have in common an emphasis on ideas and practices as powerfully mediating the effects of the environment, whether physical or

of function" (Edward W. Constant II, "The Social Locus of Technological Practice: Community, system, or Organization?" Bijker, Pinch, Hughes, *Social Construction of Technological Systems*, 223-242, at 231).

⁶³fn some poli sci: Wendt, Katzenstein volume, Minn. volume.

social. In other words, historically determined understandings and practices shape actors' attention to and the meaning of environmental "constraints" and "incentives." These approaches do not deny that there is a "there" "out there,"⁶⁴ but they do claim that this reality cannot be understood or manipulated *independently* of socially shaped ideas and practices.

I do not want to argue for the general superiority of an analysis based on frames over other social constructivist approaches. Instead, I want to locate "frames" in relation to some other approaches, and explain why an analysis based on frames is particularly well-suited for the kind of analysis in which I am engaged.

Paradigms. The conception of frame, whether "technological," as defined by Bijker, or "organizational," as I have defined it, is closely related to the idea of paradigm, as developed in the work of Thomas Kuhn and to the idea of "thought community" as developed earlier in the work of Ludwik Fleck.⁶⁵ Of course, paradigm is not a crystal-clear concept. Kuhn acknowledges that he uses the term "in at least twenty-two different ways,"⁶⁶ but argues that he mainly means it in two senses: "On the one hand, it stands for the entire constellation of beliefs, values, techniques, and so on shared by the members of a single community."⁶⁷ This is close, at least in spirit, to

⁶⁴some do seem to go this far (cites?), but i do not. cite Searle....

⁶⁵Bijker writes that his notion of frame is rooted in Fleck's conceptions (Wiebe E. Bijker, "The Social Construction of Bakelite: Toward a Theory of Invention," in Bijker, Hughes, Pinch, eds., *The Social Construction of Technological Systems*, fn 4, p 186; Kuhn first encountered Fleck, in the untranslated German, in the stacks of Widener Library at Harvard. Kuhn writes that he is indebted to Fleck's work, which made him realize the importance of the sociology of the scientific community (*The Structure of Scientific Revolutions*, 2d ed., Enlarged [Chicago: University of Chicago Press, 1970 (orig. pub. 1962)], p. vi-vii). [chk: Kuhn's intro to Fleck]

⁶⁶Kuhn, *Structure of Scientific Revolutions*, 2nd ed., p. 181.

⁶⁷Kuhn, *Structure of Scientific Revolutions*, 2nd ed., p. 175. [work in: Dessler says that Kuhn later calls this a disciplinary matrix. he says this in postscript to 2nd edition. and he reserves the term "paradigm" for exemplar.]

Bijker's definition of a technological frame and to Fleck's definition of a "thought community."⁶⁸

On the other hand, a paradigm is an "exemplar," a model embodying the solution to a puzzle which stands as an example for others to follow.⁶⁹ Kuhn refers to scientific models, but the idea holds as well for technological models or artifacts. For example, the atomic bomb is a highly complex solution to many puzzles regarding the harnessing of atomic matter for destructive purposes. And, more relevant here, the government's handbook on the physical vulnerability of structures exemplified a solution to the prediction of blast damage from atomic weapons. The two meanings of paradigm are closely related: an exemplar is likely to embody the ideas and practices of a community.⁷⁰

I use frames more in the first sense, as common ideas and practices by those in an organization or sub-organization. In my use, frames can produce exemplars; an exemplar results from a way of knowing and doing and, at the same time, embodies a way of knowing and doing. Thus, the government's handbook codifying the vulnerability of types of structures to the blast effects of nuclear weapons embodies a methodology based on blast analysis and results from a blast frame.⁷¹

So, why do I not refer to organizational paradigms (defined as common and ideas and practices by an organization or sub-organization)? It would surely be possible to define paradigm for my purposes to analyze the different

⁶⁸put in Bijker's and Fleck's definitions. Explain how Bijker differs from Kuhn: frame not attached to a single community. People can hold more than one frame and may be more or less deeply imbued with a frame. say better. say I follow Bijker on this.

⁶⁹Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 2d ed., Enlarged (Chicago: University of Chicago Press, 1970 [orig. pub. 1962]), p. 175.

⁷⁰Dessler says only partially though. ask him exactly what he means by that.

⁷¹see Orlokowski's nice distinction. (SCOR talk, winter 94/95).

organizational understandings of the damaging effects of nuclear weapons. However, although paradigms need not refer to large and totalizing beliefs and practices, such as those associated with Copernicus, Newton, or Einstein,⁷² the idea nonetheless tends to connote it. Conversely, frames have been developed in the sociology of technology literature to analyze and explain the different practices and conceptions built up around artifacts no more high faluting than celluloid and bakelite -- about as mundane as analytical systems developed for use in predicting nuclear weapons effects. The concept of frames fits well what I am trying to explain, in two senses: first, it easily describes the practices and conceptions of two quite distinct communities of engineers, and second, it translates well into an organizational context in which ideas become embedded in organizational routines.⁷³

Discourse. Although the concept of paradigm is widely used, probably the most prominent interpretive approach in social science today is based on the concept of discourse, drawn largely from the work of Michel Foucault. Discourse is a difficult concept. Not unreasonably, many assume that it refers to language. But Foucault means much more than this. Discourse is a system of meaning embedded in words, categories, practices, and institutions that structures knowledge, such as academic disciplines, and the objects constituted by those structures of knowledge. Systems of classification -- for example, categories of mental illness -- are understood as psychiatric knowledge and as true statements about people in the world. Discourse is a noun, but it is better understood as a verb, as constituted by discursive practices, which are "embodied in technical processes, in institutions, in

⁷²Kuhn, *Structure of Scientific Revolutions*, pp. 180-181.

⁷³Paradigms: Nelson and Winter in Dosi I think it is. who else in org. studies?

patterns for general behavior, in forms for transmission and diffusion, and in pedagogical forms which, at once, impose and maintain them."⁷⁴

Discursive explanations have been elegantly used in recent studies of the World Bank, the Lawrence Livermore National Laboratory, computing after World War II, and chemical weapons.⁷⁵ No doubt, such an explanation could be deployed to explain the knowledge developed about the effects of nuclear weapons. Indeed, we need substitute only two words in James Ferguson's argument regarding the World Bank to arrive at a project close to the one I have undertaken: "[Military] institutions generate their own form of discourse, and this discourse simultaneously constructs [nuclear weapons] as a particular kind of object of knowledge, and creates a structure of knowledge around that object."⁷⁶

So why do I use a notion of frames and not of discourse? The answer may lie partly in the apparently accidental pattern of my reading, in which Fleck, Kuhn, and Bijker have occupied my attention more than has Foucault. (But perhaps this is not so accidental. Foucault focuses on the human

⁷⁴Michel Foucault, *Language, Counter-Memory, Practice*, (Ithaca: Cornell University Press, 1977), p. 200, quoted in Richard Terdiman, *Discourse/Counter-Discourse: The Theory and Practice of Symbolic Resistance in Nineteenth-Century France* (Ithaca: Cornell University Press, 1985), p. 56. Other useful discussions of discourse can be found in Mark Philp, "Michel Foucault," in Quentin Skinner, ed., *The Return of Grand Theory in the Human Sciences* (Cambridge: Cambridge University Press, 1985), pp. 65-81; other cites? ["The concept of discourse, used in the sense that Michel Foucault developed, is the structure of terms, categories, and institutions that constitute the presumably self-evident truths that organize power relations in any particular historical context." Emily S. Rosenberg, "Walking the Borders," *Diplomatic History* 14 (Fall 1990): 568; "...dominant discourse -- words, practices, institutions --" Joan Scott, draft of "The Evidence Experience," in *Critical Inquiry* (Summer 1991): 35 of draft.

⁷⁵For such explanations applied to contemporary organizations, see especially James Ferguson, *The Anti-Politics Machine: "Development," Depoliticization, and Bureaucratic Power in Lesotho* (Cambridge: Cambridge University Press, 1990; Minnesota: University of Minnesota Press, 1994); also see Hugh Gusterson, *Testing Times, subtitle* (Berkeley: University of California Press, forthcoming), Paul Edwards, *look up title on my desk* (Cambridge: M.I.T. Press, forthcoming); and Richard x. Price, *blah blah* (who's publishing?, forthcoming).

⁷⁶Ferguson, *Anti-Politics Machine*, p. xiv. [Dessler notes this is just one step in Ferguson's argument.]

sciences and Kuhn on the physical sciences; Foucault on the unintentionality of discursive practices, Fleck, Kuhn, and Bijker on purposive problem-solving.) More important, however, is that the approaches explain different things. Certainly, the historically conflicting understandings of the primary cause of damage by nuclear weapons can be analyzed as part of a discourse in which nuclear weapons were understood as objects for which it made sense to engage in finely detailed "practical" calculations of damage, calculations undertaken not only to gain scientific understanding but to provide the basis for possible use -- just as damage calculations were applied in bombing operations in World War II. Further, one could reasonably explain how differences in conceptions of the cause of damage reinforced the basic discursive assumptions regarding the larger war-fighting purposes of nuclear weapons. However, for my purposes, this level of agreement and reinforcement at the level of discourse is background, context, for my puzzle regarding how one set of understandings and practices regarding damage prediction "beat out" another. In sum, discourse is background for a more conflictual analysis.

Culture. Two other approaches have been recently prominent in political science.⁷⁷ **do paragraphs on culture.**

Epistemic communities. **do. condense material in separate draft.**

In sum, paradigm, discourse, and culture connote larger interpretive frames than the particular knowledge-laden routines I examine. The concept

⁷⁷ para on culture (with an affinity toward discourse): use Kier and Legro especially. Maybe other IS piece. Elizabeth Kier, in _____ (Princeton University Press, forthcoming), powerfully uses a cultural explanation to blah blah blah. Also see Legro's cultural explanation of ----. Although cultural explanations are used in political science and in the organizational behavior literature, they are no longer used in the discipline that first developed them, anthropology, on the grounds that the concept is too vague and too static. Instead, drawing on Foucault, anthropologists have turned to discursive explanations.

of frames also offers great flexibility in that the frame or frames to be discussed can be broadened or narrowed depending on the particular problems actors are trying to solve. In addition, the notion of frames conveys precisely the *purposive* action I am interested in (what problems are actors trying to solve?) and, at the same time, the *implicit* knowledge of which actors may not be aware (assumptions about the world, about organizational purpose, and about the casting of problems and solutions).